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WOOD WASTE DISPOSAL AND UTILIZATION

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Oregon State University

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Wood Waste Disposal and Utilization

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Community Air Pollution Demonstration Project Grant A-57-941

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Corvallis, Oregon

106

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	vii
SUMMARY AND CONCLUSIONS	1
Wood waste incineration practices	1
Economics of utilization of wastes	3
PART I. INCINERATION OF WOOD WASTES	6
INTRODUCTION	6
HISTORY OF WOOD WASTE BURNERS	9
MECHANICS OF COMBUSTION IN THE WASTE BURNER	12
Combustion of wood	12
Effect of variation in fuel feed rates	12
Proportion of underfire air	13
Introduction of overfire air	14
Other variables	15
EXPERIMENTAL METHODS AND EQUIPMENT	16
Measurement of cinder discharge	16
Flue gas velocity and temperature	20
Flue gas analysis	20
Development of testing procedure	21
RESULTS	30
DISCUSSION OF RESULTS	58
Mill 1	59
Mill 2	60
Mill 3	60
Mill 4	61
Mill 5	61
Mill 6	61
Mill 7	62
Mill 8	62
BIBLIOGRAPHY	63

TABLE OF CONTENTS

	Page
PART II. ECONOMICS OF WOOD RESIDUE UTILIZATION	68
INTRODUCTION	68
QUANTITY OF MATERIAL AVAILABLE	69
Example of use of Figure 45	72
POSSIBLE USES AND ECONOMIC CONSIDERATIONS	73
Possible uses	73
Economic considerations	74
ESTIMATING COSTS OF PRODUCTION	76
Range of investments	76
Use of estimating sheets	79
Rule of thumb method	80
Conversion factors	82
Volume	82
Weight	83
Example problems using rule of thumb method	83
Transportation	85
BIBLIOGRAPHY	87
REFERENCES	89
APPENDIX	91

ILLUSTRATIONS

Figure		Page
1	Typical Steel Waste Burner	6
2	Burner Emitting Objectionable Smoke	7
3	Cinders on Restaurant Driveway, Eugene Area	8
4	Cinders on Store Walkway, Eugene Area	8
5	Thirty-Day Collection of Cinders in Gutter, Eugene Area	8
6	Cinder Fallout on Car At Restaurant After 15 Minutes. One-Quarter Mile to Nearest Burner, Eugene Area	8
7	Drawing of Modified Aerotec Dust Collector	17
8	Sampler Resistance Versus Exit Velocity	18
9	Velocity Head at Burner Top Versus Exit Velocity	19
10	Ladders and Scaffolding Constructed for Preliminary Tests	21
11	Test Equipment Installed at Burner Top	22
12	Diagram of Equipment Used at Top of Burner	23
13	Distillation Apparatus	24
14	Test Equipment	25
15	Test Equipment at Mill Site	25
16	Percentage of Excess Air for Various CO_2 Percentages in Exit Gas for Douglas Fir Fuel	28
17	Relationship of Gas Volume to Percent CO_2 for Douglas Fir Fuel	29
18	Daily Log, Mill 1, Run 1	31
19	Daily Log, Mill 1, Run 3	32

ILLUSTRATIONS

Figure		Page
20	Daily Log, Mill 1, Run 4	33
21	Daily Log, Mill 1, Run 5	34
22	Daily Log, Mill 1, Run 6	35
23	Daily Log, Mill 2, Run 7	36
24	Daily Log, Mill 2, Run 8	37
25	Daily Log, Mill 3, Run 9	38
26	Daily Log, Mill 3, Run 10	39
27	Daily Log, Mill 4, Run 11	40
28	Daily Log, Mill 4, Run 12	41
29	Daily Log, Mill 5, Run 13	42
30	Daily Log, Mill 5, Run 14	43
31	Daily Log, Mill 6, Run 15	44
32	Daily Log, Mill 6, Run 16	45
33	Daily Log, Mill 7, Run 17	46
34	Daily Log, Mill 8, Run 18	47
35	Daily Log, Mill 9, Run 19	48
36	Relation of Excess Air to Exit Gas Temperature	49
37	Average Draft Ratio of Burners Tested	50
38	Average Daily Cinder Emission of Burners Tested	51
39	Relationship Between Smoke Condition and Excess Air	52
40	Condition Observed as "No Smoke"	53
41	Condition Observed as "Slight Smoke"	54
42	Condition Observed as "Moderate Smoke"	55
43	Condition Observed as "Heavy Smoke"	56
44	Sawmill Wastes and Residues	70

ILLUSTRATIONS

Figure		Page
45	Residue Production by Mill Site	71
46	Uses for Material Now Burned	73
47	Legend for Range of Investment Sheet	77
48	Range of Investment Sheet	78

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WOOD WASTE DISPOSAL AND UTILIZATION

By

R. W. Boubel, M. Northcraft, A. Van Vliet, and M. Popovich

SUMMARY AND CONCLUSIONS

The objective of the research and of this publication was the development of information which could be applied in a practical manner to materially reduce nuisance created by fallout of cinders and other unburned materials from wood waste burning operations.

Part I of this publication concerns a study of sawmill waste burners conducted by the Engineering Experiment Station at Oregon State College. Part II is a critical study of the wood waste market and cost of delivery to markets, with the view in mind of encouraging utilization of materials now burned.

Wood waste incineration practices

The study involved critical examination and appraisal of several sawmill waste burners fired with Douglas fir waste products. The objective was to obtain information which could be applied toward substantial reduction of discharge of unburned material from these burners. Although a great deal has been published concerning design and construction of various types of burners and incinerators for wood waste, there is a lack of information from the air pollution viewpoint concerning the effect of design and operating variables.

Necessary equipment was assembled and test and computation methods were developed to perform a thorough test of each burner. Eight waste burners were tested, but on only one burner was an attempt made to control any of the variables. Tests for the other seven burners were conducted with the burners fired as determined by the mill operator.

Results of tests are presented for comparison purposes by curves, tables, and photographs. From results of this study, effect of variables may be determined and applied to other waste burners of similar design.

It may be concluded from results of this report that no burners operate perfectly. A perfect waste burner would be one which never emitted smoke or unburned material in any form. From a critical examination of facts available, however, it appears that some burners are doing a reasonably good job of consuming waste products; others are discharging objectionable quantities of unburned materials.

All burners tested smoked at the start of the day's operation; some for only a short period of time, whereas others smoked most of the day. Amount of excess air seemed to be the main variable with which smoking and cinder fallout could be correlated. On two of the burners, merely closing the access doors resulted in a decrease in both smoke and cinders. Burners having excessive overfire air because of buckled plates, cracks, and oversized air openings, had excessive smoke and cinder emission. It may be concluded, therefore, that for a given burner the less excess air over that necessary for proper combustion, the cleaner the atmospheric discharge. For good combustion and low cinder emission, excess air should be held between 300 and 500 percent. All offending burners tested could be repaired so they would operate with excess air controlled within the desired range. They should be fired with the door tightly closed at all times to further reduce excess air.

Tangential inlets of overfire air are a definite advantage in promoting proper combustion and reducing fallout of unburned material. None of the burners having properly designed tangential air openings was emitting an excessive amount of unburned material. Existing burners could be provided at small cost with tangential air inlets, which would definitely increase their efficiency. Leaving the door open on a burner equipped with tangential air openings tends to break up vortex action, and should not be permitted while the burner is operating.

A definite correlation existed between smoke and cinder output. It was determined that a smoking burner also was emitting unburned particles of larger size, and any measure that would decrease density of smoke would decrease quantity of cinders being emitted.

Because the heaviest smoke occurred during startup, any means which would increase the temperature during that time would decrease both smoke and cinders. Therefore, a good fire should be built and ignited each morning before the mill starts

operation. The first fuel entering the burner would then ignite instead of piling up until the temperature became high enough to ignite it.

The burner should be kept free of both ashes and clinkers in order to allow the forced draft system to function as it was intended. This means the grates should be cleaned periodically. Most of the forced draft systems were found to be completely or partially plugged due to excessive ash beds.

Correct size of burner in relation to a given mill production or quantity of waste is difficult to predict because many variables must be taken into consideration. Although some burners appeared at first glance to be overloaded, further analysis indicated that excessive cinder emission was probably caused by other variables which created poor combustion conditions within the burner. Nevertheless, examination of cinder discharge data indicated that satisfactory operation was obtained with some burners at daily loading rates as high as 100 pounds of fuel per square foot of base area.

Further studies in waste burner design and firing methods are justifiable, and Oregon State College Engineering Experiment Station plans to continue these.

Economics of utilization of wastes

It is not an easy task to completely eliminate a sawmill burner. Today, the small mill cannot utilize all of the material going to the burner—tomorrow, this goal of the industry may be attained.

As mentioned in Part I, many of the materials causing burner problems are the very wood residues that have not gained economic value. Although there are technological developments, local uses, or integrated operations to speed utilization of wastes and residues, current times and economics often dictate the pace.

When it came to improved practices, the common cry in the past was, "Let George do it!" The small mill owner today cannot afford this attitude. It is time to move, even though slowly, in the wood utilization direction. High labor and raw material costs make mandatory some movement for survival.

Part II is a cautious stimulant designed to interest the

mill owner in present and future possibilities of utilization. Several useful estimating sheets and formulas are given as guides to economic feasibilities of an idea. If interest is created, the mill owner now can turn to helpful references and organizations for assistance in fulfilling his plans.

Figures used in Part II of this report, through necessity, have been based on industrial and regional averages. There is no such thing as a perfectly average sawmill, just as there is no perfectly average person. The point must be stressed again that each sawmill presents an individual situation and, as such, given averages must be adjusted to meet these particular needs. If the mill owner has kept proper records of the mill's operation, he is able to see what changes in the "average" will give him information to use in his own particular situation.

Differing market conditions play a leading roll in determining the type of end product to be manufactured. Before final selection of a manufacturing process, it is up to the mill owner to ascertain marketability and indicated monetary return for his proprosed product. Due to variability of markets between geographical areas, it is again necessary for the producer to make his own survey of local market conditions, and not to depend exclusively on prepared averages.

One method of meeting market fluctuation in any business is through product variation. By being able to increase or decrease production within a group of products, the mill owner can take advantage of market inequalities. By considering and investigating a number of possible uses for residue, he can see where the greatest demands and the largest returns are encountered. It is quite possible to reach a point of market saturation when too many mills decide to produce the same item.

There are a great number of possible uses for residue, but only a small portion of them have been detailed in this report. Many uses are feasible only in certain localities, and it is up to the mill owner to discover these for himself. Certain mills have reached an extremely high degree of utilization by taking advantage of local needs and exploiting these needs to their fullest extent. Within the next few years, certain utilization practices now uneconomical will prove commercially practicable, and will open new areas for utilization of mill residue.

Mention might be made of future prospects for the residue problems of small mills. It now is evident that small-mill

chipping is in the immediate future in this region, and future economic conditions may allow for growth of slab concentration yards, as found in the South. Wide use has been made of these concentration yards in certain areas of the country, but as yet they have had limited development in the Pacific Northwest. Transportation costs and certain other factors have limited the growth of this type of yard. Heavy increase in demand for pulpable material could bring this type of operation into its own.

Investment-wise, it is assumed all equipment and buildings are new, and no costs are shared with existing installations. It is at this point that the mill owner may be able to cut his costs by wise buying and ingenuity. He may be able to use reconditioned machinery, or improvise with equipment and buildings already on hand.

This report is intended as a tool for use by the mill owner in building improved utilization practices. No one person can set down the solution to every mill's problems in one report; rather, it is up to the mill owner to use the tools given him to work out his individual problems. It is time to realize that in these days of high raw material costs, the mill is paying for the whole log and there is no money refunded for the unused portion. The refund is in the owner's hands, and can be realized only by utilizing all the log that sound economics will allow.

PART I. INCINERATION OF WOOD WASTES

INTRODUCTION

In the manufacture of lumber in most sawmills, approximately 50 percent of the log is residue or waste material. This means that for every 1000 fbm of lumber produced, approximately 1 ton of wood product is logged, transported, and then discharged in some manner into waste. Waste products are in the forms of coarse residue, sawdust, shavings, and bark.

Many useful by-products have resulted from utilization of these waste products. Among the more common are slab fuel, hogged fuel, laths, Presto logs, broom-handle stock, and bark-free pulpwood for manufacture of paper.

Although most lumber manufacturers utilize waste products to some degree, utilization varies from 0 to 100 percent (as claimed by some manufacturers). Incineration is the method of wood waste disposal used by most lumber manufacturers whose utilization is something less than 100 percent. The most widely used type of incinerator is the tepee-shaped, single-walled, steel waste burner pictured in Figure 1.

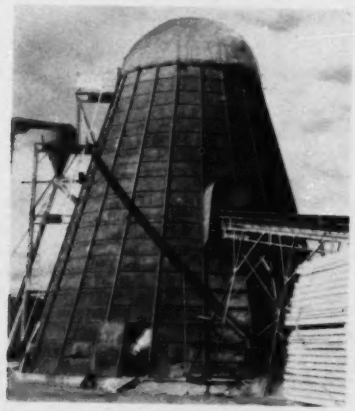


Figure 1. Typical Steel Waste Burner

Tepee-type waste burners at some operations have done a creditable job. Waste products delivered to the burners have been consumed with only a minimum of smoke and cinders (unburned material) issuing from the top with the exit gases. At other operations, the great quantities of smoke produced have caused hazardous visibility conditions for automobile and air travel. Cinders ejected not only have created a nuisance to owners of property in surrounding areas, but also have constituted a fire hazard.

Figure 2. Burner Emitting Objectionable Smoke

Most owners of sawmill waste burners recognized that a problem existed, but could offer no solution. Recommendations for size and configuration varied with burner manufacturers, mill owners and operators, and insurance underwriters. As a result, the task of determining what constituted an offending burner rightfully fell to the Air Pollution Authority.

A sawmill waste burner study was initiated at Oregon State College in June 1957, with the objectives of determining the optimum size of burner for a particular operation, and of observing the effects of certain operating variables. Some phases of the investigation are still in progress, but because of the interest shown in the findings and recommendations to date, this report is being presented at this time. An additional report will be presented when future studies are completed.

It should be recognized that the lumber industry is one of the greatest contributors to Oregon's economy. Because of present

day market conditions, changes in operation or design of waste burners involving major expenditures could result in closure of many sawmills. Bearing in mind present economic conditions, waste burner studies were concentrated upon the relatively inexpensive, tepee type in common use.

Figure 3. Cinders on Restaurant Driveway, Eugene Area

Figure 4. Cinders on Store Walkway, Eugene Area

Figure 5. Thirty-Day Collection of Cinders In Gutter, Eugene Area

Figure 6. Cinder Fallout on Car at Restaurant After 15 Minutes. One-Quarter Mile to Nearest Burner, Eugene Area

HISTORY OF WOOD WASTE BURNERS

During the first 20 years of the 20th century, many types of waste burners were designed. Some were designed for complete combustion, some for low initial cost, and others for low maintenance. Most accounts described design and construction of new burners and predicted results, but actual success of operation or economy of maintenance of burners which had been in operation an appreciable length of time was seldom mentioned.

The steel-jacketed, brick-lined, cylindrical burner was perhaps the most common type. A shell made from steel boiler plates was lined with common brick and firebrick in the following manner: Two courses of common brick and 1 course of firebrick from the base upward for 15 feet; 1 course of common and 1 of firebrick from 15 feet to 40 feet; 1 course of firebrick from 40 feet to 75 feet; and 1 course of common brick above 75 feet (8). Foundations were made of brick or concrete, and often consisted of a central core several feet in diameter and an outer base on which the burner rested. There were grates between core and base. Fuel dropped from about 40 feet onto the central core. Top of the burner was covered with a 3 by 3 mesh, 14-gauge wire screen. Base area was from 3.5 to 5.5 square feet per 1000 board feet of mill output. Exteriors were often painted or tarred to prevent corrosion. Maintenance costs were high because the brickwork had to be replaced annually.

The concrete-shelled, brick-lined, cylindrical burners were priced from 40 to 50 percent lower than the steel-shelled, brick-lined burners of the same size.

A 63-foot diameter, 104-foot high burner constructed at Hoquiam, Washington in 1916, was a good example of this type of construction (7). Temperatures in the burner ranged from 1500 to 2000 degrees F. The concrete shell around the combustion chamber was octagonal, and the inner brick wall was circular. This construction provided a considerable amount of air space, which was vented by terra cotta vents around the base and stack. The upper stack was circular for both brick and concrete, with a 1-inch air space vented by a 1-inch galvanized pipe. A corbeling-in of the brick toward the stack at the top of the combustion chamber improved draft and reflected heat back into the combustion chamber, thereby maintaining high temperatures for excellent combustion. The concrete foundation of the burner was covered with a

layer of firebrick laid flat, with no grates or underdraft.

Four 20- by 20-inch iron doors, which extended through both walls about 19 feet above the base, were used to control rate of burning and, to some extent, temperature of the brick lining. Air admitted at this point decreased draft at the base and cooled the stack gases. Air was admitted to the fire through four short T-shaped tunnels located at ground level. Outer ends of three of the tunnels were firebricked walls facing the fire.

Concrete was selected as shell material because a previous steel-jacketed burner had corroded rapidly due to exposure to salt air. Also, cost of a concrete shell was only half the cost of a steel shell the same size. Thermal tests were made on the concrete before construction and, as an added precaution, special ventilation was given to the shell.

The shell was 10 inches thick. The brick lining was 8 inches thick, separated from the shell by a 4-inch air space, and supported every 4 feet, up and across, by a brick projecting out against the concrete shell. An 8-inch vent was left about every 4 feet around the top and bottom to allow passage of air through the air space. The inner wall was merely common brick laid in common clay to form a glaze. Cost of the structure was $17,000.

Another example of a concrete shell burner was one built in 1919 in San Francisco (33). It was designed for destroying planer shavings and sawdust, and for low first cost and long life. It consisted of a firebrick-lined concrete shell, 14 feet in diameter at the base and 60 feet in height. Fuel was blown in through an 18-inch feed pipe. As much as 400 cubic yards of refuse were consumed in a 9-hour period.

Special design features were the means provided for expansion of the brick and ventilation of the concrete, thus increasing life of the burner. The concrete shell was made in two pours. The brick lining was installed in two separate sections—the upper section resting on a concrete shelf so that it was independent of the lower section. The most important design feature of this burner was the expansion joint separating the two brick sections.

The fourth tunnel had an iron door provided for clean-out purposes and for firing fuel too large for the blowers. Top of the

stack was covered with a 1/4-inch mesh wire screen to catch sparks.

Some steel, water-cooled burners were used which had no brick lining but, instead, had a watertight steel jacket surrounding the inner shell, which was from 12 to 15 inches thick. These burners were constructed in all sizes up to 50 feet in diameter and 115 feet in height. Paint and asphalt were used to protect the outer surface. Very few were built, however, because of high construction and maintenance costs.

Open pit fires were used then, as they sometimes are today. These consisted of a semicircular screen or wall rising 20 to 30 feet on the side of the fire toward the mill.

Brick shell burners were cylindrical and similar to brick-lined shell burners, except that they were shorter. Steel straps were placed around them for support.

An air-cooled burner was placed on the market in 1916. It had a conical base and a cylindrical stack without any brick lining. The foundation was a concrete wall 1 foot thick and extending 2 feet above the grate level. Framework was made of structural steel and iron pipe, with an outside covering of medium-weight steel plates riveted together. The conical shape placed the base of the burner farther away from the fire, and air circulation cooled it. These burners cost 40 to 50 percent less than brick-lined steel burners.

This was the beginning of the tepee burner commonly in use today. Most builders have abandoned the cylindrical stack and now construct burners which are conical from base to screen.

Most tepee burners have two screens at the top—a flat, horizontal screen and a hemispherical one. Tangential openings for overfire air to the fire have been used for many years, but only recently have they come into common usage. Some builders now place around the burner a 6-inch high opening, which is approximately 8 feet from the top. Underfire air is usually supplied by one or two blowers to cones in the burner grates. Some burners are elevated to provide tunnels below the grate level to admit underfire air.

The practice of building prefabricated burners has been developed since 1946. These are built in sections, running from

the base to the screens. Structural framework is on the outside, with the plates on the inside. The burners are raised into place on location and bolted together in a short time. They can be dismantled easily, transported, and resold.

MECHANICS OF COMBUSTION IN THE WASTE BURNER

Combustion of wood

Although a great amount has been written about the mechanics of combustion of both wood and hogged fuels, very little information is available regarding desirable combustion practices in the steel, tepee-type, wood waste burner. To understand the particular problems involved, the logical starting point would be an examination of the fundamental mechanics of wood combustion.

Combustion of wood containing moisture falls into a definite series of steps, each of which must be considered.

1. Wood contains moisture which must be evaporated. This process requires heat and, hence, is strictly endothermic.

2. Wood contains volatile matter consisting primarily of compounds of carbon, hydrogen, and oxygen, which must be distilled. This process of distillation is endothermic but, once distillation takes place, an exothermic reaction occurs as the volatile matter combines with available oxygen to liberate heat.

3. Wood contains fixed carbon which combines with oxygen exothermically. Remaining material in the wood is considered as ash because it is noncombustible.

When applied to the waste burner, these steps take place as follows: As fuel is admitted to the burner it falls to the fuel pile, where heat must be applied before any combustion takes place. Once the wood is dried, distillation of volatile matter is accelerated. This volatile matter burns in the space above the fuel bed. The final stage of combustion is completed when all fixed carbon has combined with oxygen in the fuel bed, or in the air stream if the particles are picked up and carried upward before they are completely burned.

Effect of variation in fuel feed rates

The ideal situation would have the moisture driven off,

volatile matter distilled and burned, and fixed carbon burned at the same rate fuel is supplied. This situation would require a uniform rate of fuel feeding, along with a uniform rate of combustion, and seldom can be achieved. If fuel is supplied too rapidly, more heat is needed for drying than is available from combustion of fuel already in the burner. The result is an inefficient fire, one which tends to extinguish itself.

After a fuel pile continues increasing in size from an abnormally high input, a decrease in fuel input invariably occurs and the heat available exceeds that needed for drying the fuel. The rapid combustion which results generates a great amount of heat in a short period of time. Extreme heat release rates result in buckling of plates and structural members of the burner.

While fuel is being admitted faster than it is being burned, much more air is admitted to the burner than is needed for combustion. This excess air also tends to cool the fire and contributes further to poor combustion. If excess air could be decreased, more heat would be available to drive moisture from the fuel. When the fuel input rate exceeds the combustion rate for a period of several minutes, a large quantity of smoke and cinders may be expected because temperature within the burner is not high enough to permit complete combustion before combustible material reaches the exit of the burner.

With proper combustion; i.e., with fuel burned at the same rate it is fed and with a relatively small amount of excess air, temperature within the burner should be high enough to allow nearly complete combustion of all material before it is discharged from the top of the burner.

Proportion of underfire air

Heat necessary for drying the fuel must come from the following:

1. Hot gases and radiant heat from fuel pile.
2. Radiant heat from surrounding surfaces.
3. Heat available from incoming air.

Because of rapid heat transfer through the steel in waste burners, there is very little radiant heat available from the walls

to dry the fuel. There also is very little heat available from incoming overfire air. Therefore, the only appreciable heat to dry the fuel must come from the burning fuel pile. It would be an advantage if a large percentage of combustion air could be forced through the burning fuel. This not only would hasten combustion of the fixed carbon, but would force the hot gases through the moist fuel and would allow more heat for drying the fuel than when using all overfire air.

Fixed carbon which must be burned in the fuel pile constitutes about 17 percent of the weight of the dry fuel. Therefore, enough oxygen to consume this percentage of fixed carbon should be supplied to the fuel bed by a forced draft system. Computing on a percentage basis the amount of air required for complete combustion of the fixed carbon would indicate that 30 percent should be supplied by the forced draft system. This value should be used as a minimum, or, in other words, a burner should have a maximum of 70 percent of the air admitted over the fire. For a burner handling 10,000 pounds of dry fuel per hour, the forced draft system should be capable of supplying 14,500 cubic feet of air per minute at 70 degrees F against the static pressure of the forced draft system and the fuel bed. All other air needed for combustion would be supplied as overfire air.

An analysis similar to the preceding was made (34), and the value of 10 percent for proportion of forced draft air to total air was given. In commenting on this article, one reviewer stated that 75 percent of the air should be admitted under the grates. The matter of ratio of air through the grates to total air should be investigated further in order to arrive at a satisfactory value that could be used as a design criterion. Even if the low figure of 10 percent is used, most existing burners have inadequate forced draft facilities.

Introduction of overfire air

Means of introducing overfire air should be an important consideration from the combustion standpoint. If overfire air is admitted through open doors, nondirectional ports, or cracks in the shell, it immediately acquires a vertical velocity component. This overfire air may be discharged from the top of the burner without ever having passed through the combustion zone. The net result is a stratification of air, gases, and steam, along with an overall excess of air.

This excess air is the main cause of emission of unburned material. In fact, vertical velocity within the burner can become so great that some of the lighter fuel particles (shavings and sawdust) may be ejected from the top of the burner without ever having passed through the combustion zone.

If all overfire air is admitted through air ports which impart a tangential velocity component, a free vortex motion of air and gases is established. Benefits of this free vortex may be summarized as follows (17):

1. Air acquires more preheat by convective heat transfer from the wall than if air had entered through a door or nondirectional ports.

2. Velocity of gas stream relative to burning charge is higher for the same net volume through the ports. This results in the following:

a) Increased combustion rates.

b) Improved mixing of air and combustible gases, which gives a shorter flame.

c) Less excess air for same combustion rate, which gives a higher flame temperature and lower stack velocity.

3. A longer path for suspended solids promotes consumption of any unburned carbon they may contain.

Other variables

The foregoing is an attempt to explain combustion problems peculiar to the steel wood waste burner. Many variables other than those discussed must be taken into consideration before an ideal design can be determined. A few of these are:

1. Type of charge (shavings, sawdust, slab, trimmings, bark, etc., and possible combinations of these).

2. Prevailing wind conditions which could affect draft.

3. Method of fuel distribution within burner.

4. Variable rate of fuel loading as affected by the operation of a particular mill.

The effect of some of these variables on design and operation of sawmill waste burners will be determined in future tests.

EXPERIMENTAL METHODS AND EQUIPMENT

In keeping with the original objective of the study, the primary measurement taken was quantity of cinder emission from a burner. At the beginning of the experimental work it became apparent that measurement of certain other variables would be of great value in correlating results of the tests.

Measurement of cinder discharge

Cinders, as defined for this report, were unburned solid material collected on a 50-mesh screen, and as such could be collected by means of a suitable collector and weighed. An Aerotec dust collector with a Clements blower and suction power unit was used for this purpose. The unit consisted of two separate collecting chambers. The first was a pint Mason jar which used a cyclonic separator to separate solid material from transporting gases. Gases were then passed on to a cloth filter bag, where the finer particles were removed from the gas flow. Gases were then exhausted from the collector through the blower.

It was found immediately that a modification had to be made because of the relatively large volume of condensed water vapor which accumulated in the collector. The modification was made by placing a 50-mesh screen within the Mason jar to collect the cinders. The cloth filter bag also was replaced with a 50-mesh screen to eliminate plugging by moist cinders. Unburned cinders collected through various tests were, therefore, the material that could be collected on a 50-mesh screen. A drawing of the dust collector is shown in Figure 7.

To collect unburned material from ground level, a piping system was devised to sample at the top of the burner and deliver to the collector. This consisted of lengths of 2-inch aluminum pipe, joined where necessary with couplings. The aluminum pipe led up to a 1-1/4 inch steel pipe at the top of the burner, which was connected to a 2-7/8 inch inside diameter sampling head.

A U-tube manometer was connected across the orifice taps of the dust collector to determine flow through the collector. A curve was drawn (Figure 8) relating quantity of gas at the collector

head (and hence velocity) to temperature of gas and pressure drop across the orifice at the collector.

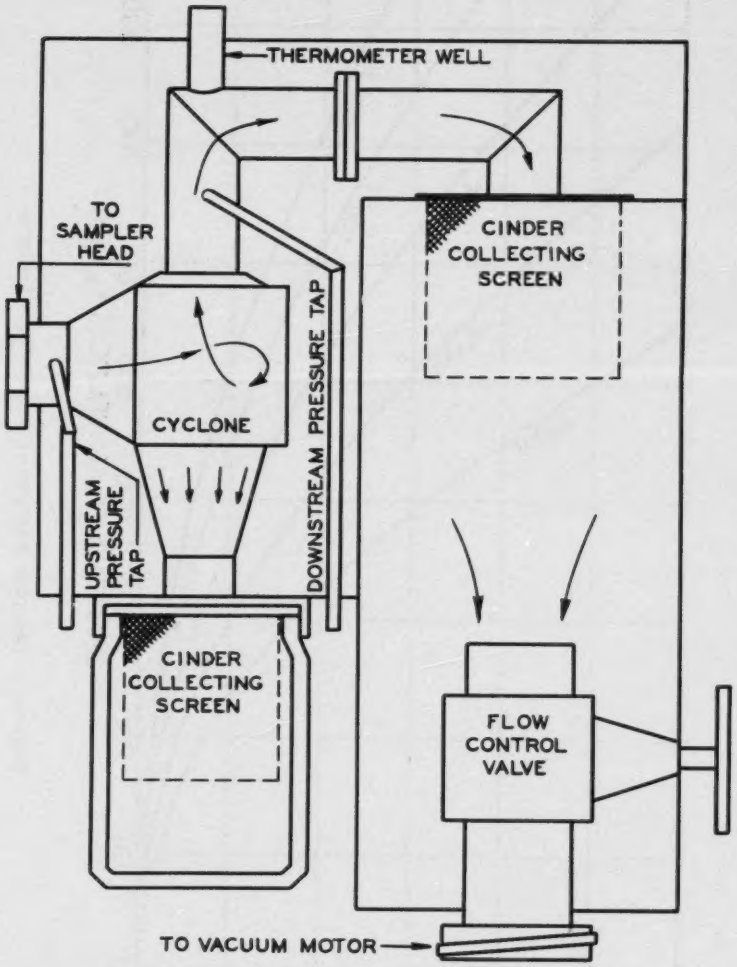


Figure 7. Drawing of Modified Aerotec Dust Collector

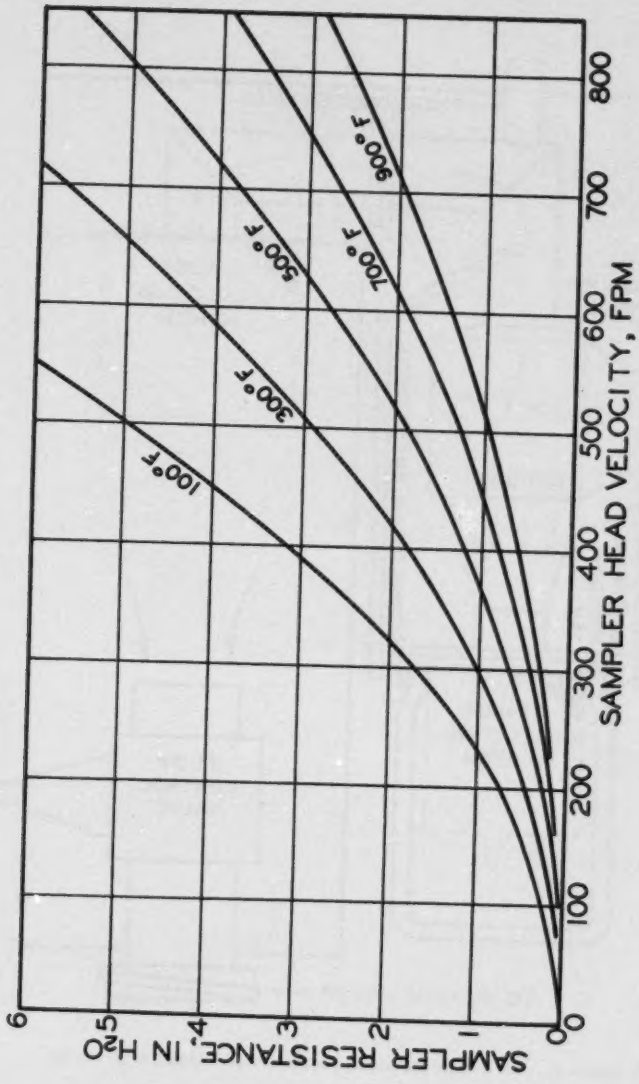


Figure 8. Sampler Resistance Versus Exit Velocity

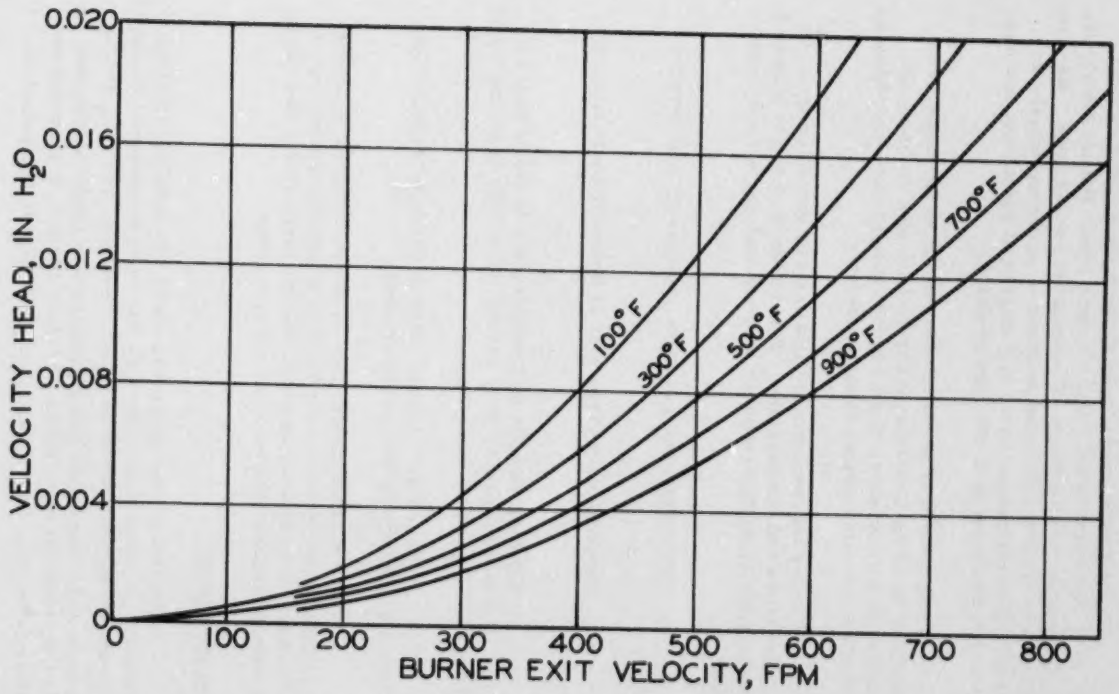


Figure 9. Velocity Head at Burner Top Versus Exit Velocity

Flue gas velocity and temperature

To determine gas velocity at the burner outlet, a pitot-static tube was constructed from 1/8-inch pipe. Plastic tubing was used to transmit the pressure differential to ground level. Because of the extremely low velocities involved, a micromanometer was utilized. This instrument had a high degree of sensitivity and was read with a precision of 0.001 inch of water.

Temperature of gases leaving the top of the burner was determined by using a calibrated chromel-alumel thermocouple connected to a pyrometer. Cold junction temperature was taken as the ambient air temperature at the pyrometer.

A curve was constructed relating exit gas velocity to velocity pressure and temperature. This curve is shown in Figure 9. Procedure for balancing collector velocity with gas velocity was as follows:

1. Determined exit gas velocity pressure and temperature.

2. Entered curve (Figure 9) to find velocity in feet per minute.

3. Knowing velocity and temperature of gas at dust collector, necessary pressure drop across the orifice from the curve was found.

4. Adjusted flow control valve of collector until U-tube manometer read the proper pressure drop.

In this manner the velocity of gas entering the sampling head could be maintained at the velocity of gas leaving the top of the burner. This balance assured that the sample head was taking in a sample representative of the exhaust gases.

Flue gas analysis

Analysis of exit gases was made with a Hayes orsat instrument. A rubber aspirator bulb was used to transport the sample from the burner exit to the orsat. Initially, both CO_2 and O_2 readings were taken, but this procedure was simplified so that only CO_2 readings were taken. Because the fuel in all cases was primarily Douglas fir, it was a simple matter to obtain both the

percentage of oxygen and the excess air from curves, once the carbon dioxide percentage was known.

Development of testing procedure

With instrumentation completed, a testing procedure remained to be developed. All preliminary tests were made at Mill 1. A series of ladders and scaffolding was so constructed that a working platform could be placed at the burner top (Figure 10). From this platform both velocity and sampling traverses could be run across the top of the burner. During the running of the original velocity traverses it was found that no reproducible results could be obtained at the same point on the screen. This was attributed to changing combustion conditions within the burner. Temperature at one point also was found to vary as much as 100 degrees F in a 5-minute period. Velocity appeared to be fairly uniform across the entire upper surface of the burner. Temperature also seemed fairly constant across the burner.

Figure 10. Ladders and Scaffolding Constructed for Preliminary Tests

Because the top of the burner was covered with a 3- by 3-inch 16-gauge mesh, the entire burner acted as a plenum chamber.

As both velocity and temperature measurements were taken above this horizontal screen, velocity and temperature at a point about 1/3 of the top diameter from the edge was taken as the average. Sampling head, pitot-static tube, and thermocouple then were secured to the screen for all further readings.

Figure 11 shows necessary equipment in place above the horizontal screen during a test. Figure 12 is a schematic drawing of equipment used.

Figure 11. Test Equipment Installed at Burner Top

For preliminary tests, an attempt was made to log air into the burner using a rotating vane anemometer at each air intake opening. This was abandoned because no data could be taken of air leakage into the burner through cracks and other openings. It was decided instead to insert a tube at the base of the burner and determine draft within the burner. The draft then could be used to determine both burner air intake and burner condition, or tightness of construction, by comparing it with the theoretical draft the burner should produce. Draft was measured in inches of water by means of an inclined tube draft gauge.

Because of availability of only one dust collector, it was decided to run the collector continuously through an entire day's test, and then weigh the collected cinders.

Screens containing cinders were placed in a plastic bag and returned to the laboratory at Oregon State College. Screens and cinders were placed in an oven at 220 degrees F and dried to constant weight, as determined on a balance accurate to 0.1 mg.

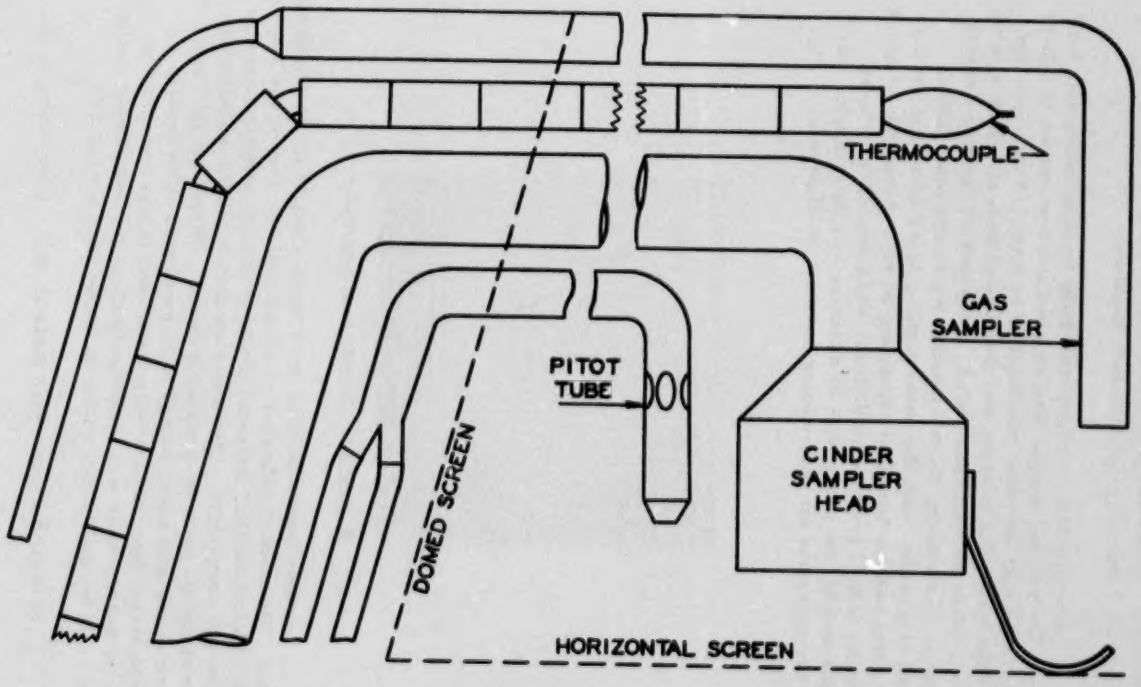


Figure 12. Diagram of Equipment Used at Top of Burner

Fuel samples were taken periodically from the sawdust at the head-rig. These samples were sealed in a Mason jar and returned to the laboratory for moisture analysis.

Moisture determination was made by distillation with kerosene. The wet fuel sample was weighed and then placed in a flask and covered with kerosene to a depth of at least 1/4 inch over the top of the fuel. The mixture was then boiled until all water was removed. When the kerosene boiled, it carried off the water with it as vapor. Condensing the two liquids, which are immiscible, caused separation, with the water settling to the bottom of the distilling trap and the kerosene remaining on top. Assuming weight of the water to be 1 gram per milliliter, and knowing the original sample weight, the percentage of moisture was determined. Distillation apparatus for determining moisture is illustrated in Figure 13.

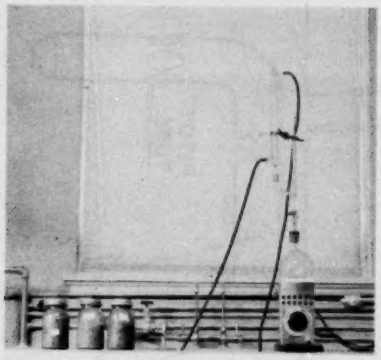


Figure 13. Distillation Apparatus

Smoke determinations were made visually on the following bases: "No smoke" indicated no smoke could be seen at the burner exit. "Slight smoke" indicated smoking was not serious enough to cause any complaints. "Moderate smoke" indicated smoking was severe enough to cause a nuisance factor. "Heavy smoke" indicated smoke was heavy enough to be extremely objectionable. These visual observations were made after it was found that no smoke density scale was available (such as the Ringelmann scale) that could be applied accurately to smoke from a wood fire.

Several test runs were made at Mill 1 after changing the

overfire air inlet. Runs were made with only draft openings open, with all draft openings and clean-out door open, and with only about 1/2 the draft openings admitting air. These changes were made in an attempt to find an ideal rate of air admission to the burner.

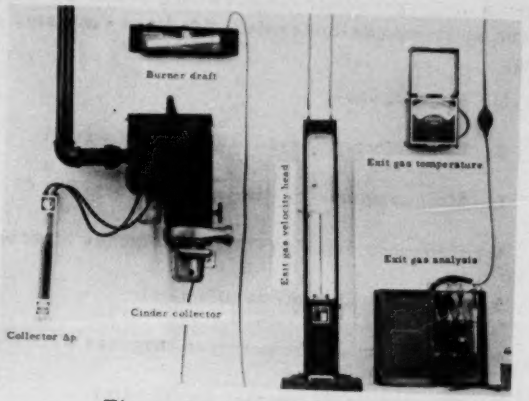


Figure 14. Test Equipment

Since all measurements were made with sampling equipment fixed firmly in place above the horizontal screen, it was decided to eliminate the scaffold in further tests. Two men could set up for a test by one working at the top of the burner and one working on the ground. All readings were taken from a central location on the ground. Instrumentation and collection equipment for a typical test is shown in Figure 15.

Figure 15. Test Equipment at Mill Site

A test procedure was developed and applied which gave reliable and fairly reproducible results. The test crew arrived at the mill site about 3 hours before start of the day's operation so test equipment could be installed on the burner while it was cool. Initial readings were taken when mill operation started. From mill startup until operations ceased at the end of the day, readings were taken at 15-minute intervals. Readings consisted of the following:

1. Time of day.
2. Exit velocity pressure (inches of water).
3. Micromanometer temperature (degrees C).
4. Collector orifice resistance (inches of water).
5. Burner draft (inches of water).
6. Cold junction temperature (degrees F).
7. Thermocouple reading (millivolts).
8. Exit gas analysis (percent CO_2).
9. Smoke density (visual).

Fuel samples were gathered periodically, and cinder collection screens changed when an appreciable quantity of cinders was collected. At the end of the day's run, all fuel samples and cinders collected were returned to the laboratory for analysis. Cinders were oven-dried, weighed, and a moisture determination made. The same procedure was repeated the second day on the same burner, except that sampling equipment was left installed in the burner, and this part of the set-up was eliminated. After the second day's run, equipment was disassembled and taken to another mill site.

Except for the preliminary runs on Mill 1, all burners were tested as they were operated normally. In no case was any attempt made by the test crew to change the method of mill operation or burner firing conditions.

All test data were returned to the laboratory at Oregon State College, where computations were made. From test and computed data it became apparent that even though readings were

taken every 15 minutes, conditions were so variable that extreme fluctuations occurred. It was decided, therefore, to utilize a method of plotting curves to eliminate the saw-toothed effect.

The method selected was to plot a progressive mean rather than just individual points. Although this procedure resulted in additional computations, it did yield a curve which could be interpreted easily.

The following are results computed from test data:

1. Exit gas temperature (from thermocouple calibration curve).

2. Exit gas velocity (from a curve relating velocity to velocity pressure and gas temperature, Figure 9).

3. Collector head velocity (from a curve relating velocity at the head to collector temperature and orifice pressure drop, Figure 8).

4. Excess air (from a curve relating excess air to percent CO_2, Figure 16).

5. Fuel loading rate (by means of a carbon balance calculation utilizing curve from Figure 17).

6. Cinder output (from relative size of collector sample head to burner exit area and daily weight of cinders collected).

7. Fuel moisture (from moisture determination).

Additional computations and tabulations made for curves for the purpose of comparing various runs and burners are:

1. Ratio of theoretical draft to actual draft.

2. Theoretical excess air versus temperature by means of a heat loss balance.

3. Relation of smoke density to excess air determinations.

The Department of Statistics at Oregon State College analyzed the data for the effect of the variables on smoke condition. Because this analysis was made mathematically, a numerical

scale was arbitrarily assigned to smoke density. Values assigned were: no smoke = 0, slight smoke = 1, moderate smoke = 2, heavy smoke = 4.

Data on the other four variables: exit gas temperature, exit gas velocity, percent CO_2, and draft, were segregated by mill and by day for each of the different smoke conditions. An average was then computed for each variable for a given mill, day, and smoke condition. A statistical analysis was carried out to determine whether or not there were day to day significant differences in these averages for a given variable, mill, and smoke condition.

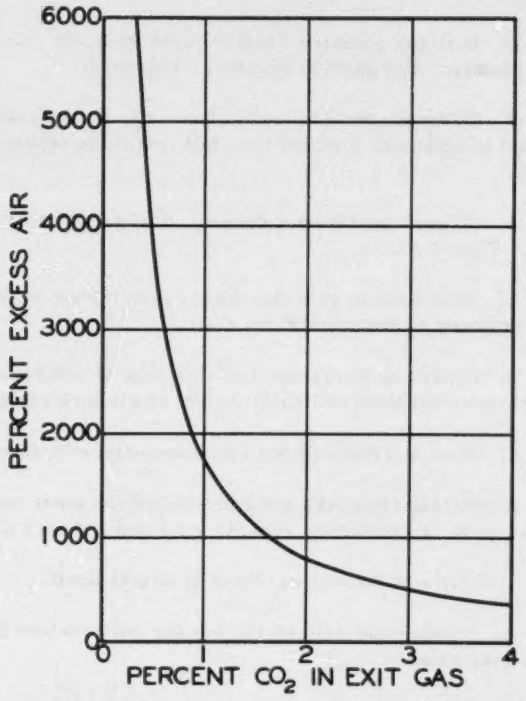


Figure 16. Percentage of Excess Air For Various CO_2 Percentages in Exit Gas For Douglas Fir Fuel

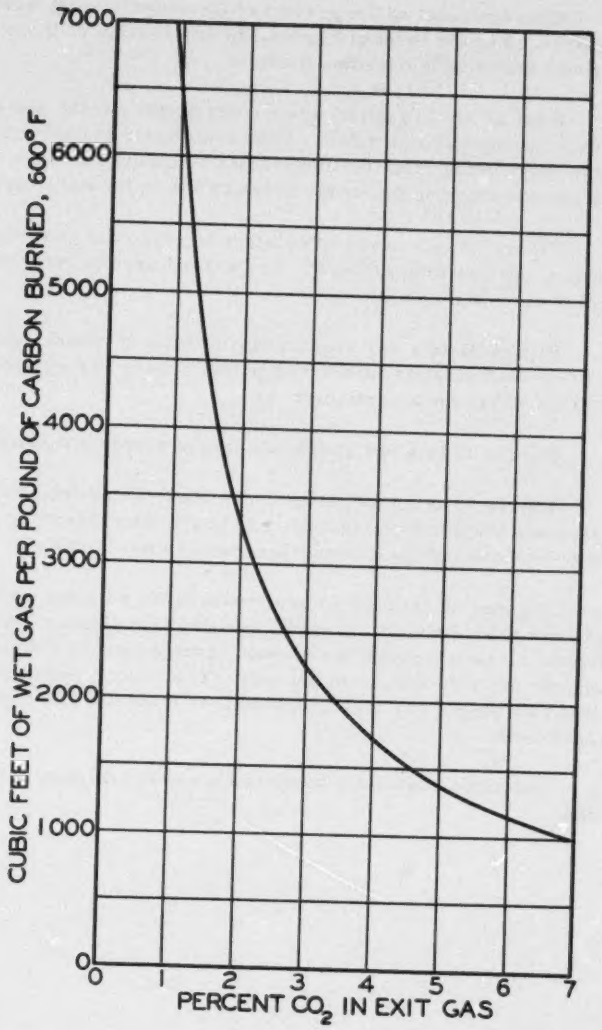


Figure 17. Relationship of Gas Volume to Percent CO_2 For Douglas Fir Fuel

RESULTS

Although most of the results of the experimental work are best expressed in the form of curves, an explanation of these curves will aid in understanding them.

Figures 18 through 35 are curves of daily tests and calculated data for the various mills. They are plotted by taking a progressive mean value from the individual 15-minute readings. The curves are arranged in the order in which the mills were tested.

Figure 36 is a curve of computed excess air plotted as a function of exit gas temperature. The shaded area represents 95 percent of test data points.

Figure 37 is a bar graph showing ratio of actual draft (measured) to theoretical draft (computed). Each bar represents the average value for a particular mill.

Figure 38 is a bar graph of average cinder emission.

Figure 39 is a composite curve constructed from all data. It represents the smoke condition, and hence the cinder emission that may be expected for varying percentages of excess air.

Figures 40 through 43 are photographs relating cinder density to smoke density. In each case the first photograph is of the burner as seen through the normal camera lens at a distance of approximately 40 feet from the exit. The second photograph was taken through a 250 mm telephoto lens from the same point at the same time.

The table contains a tabulated summary of significant test data.

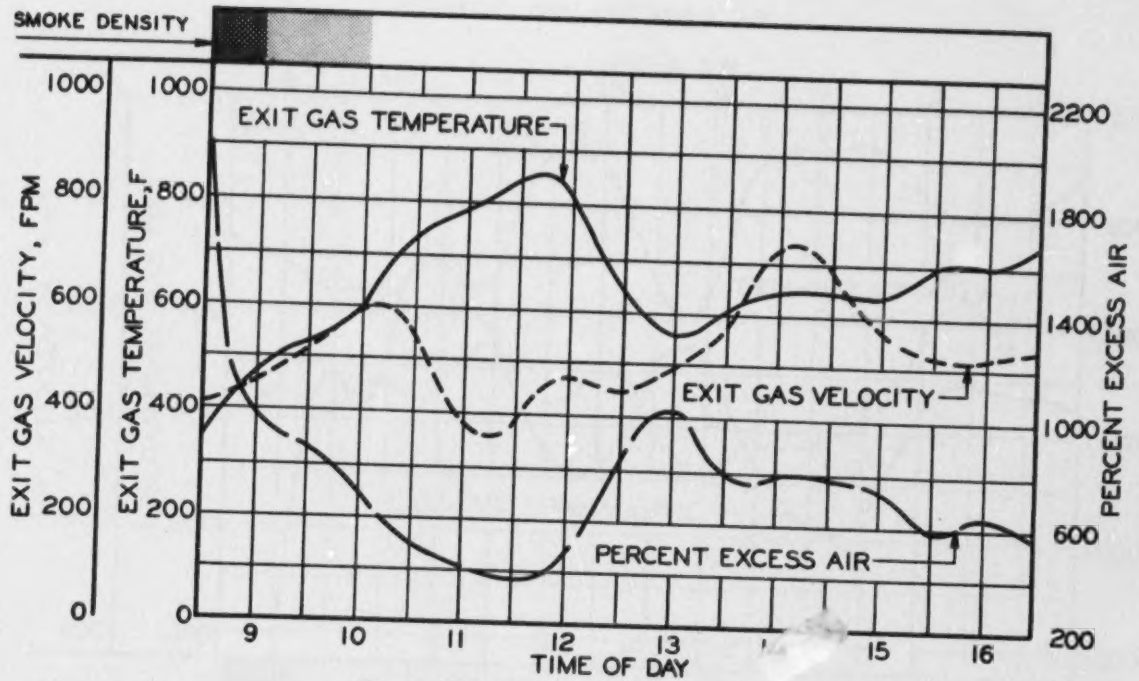


Figure 18. Daily Log, Mill 1, Run 1

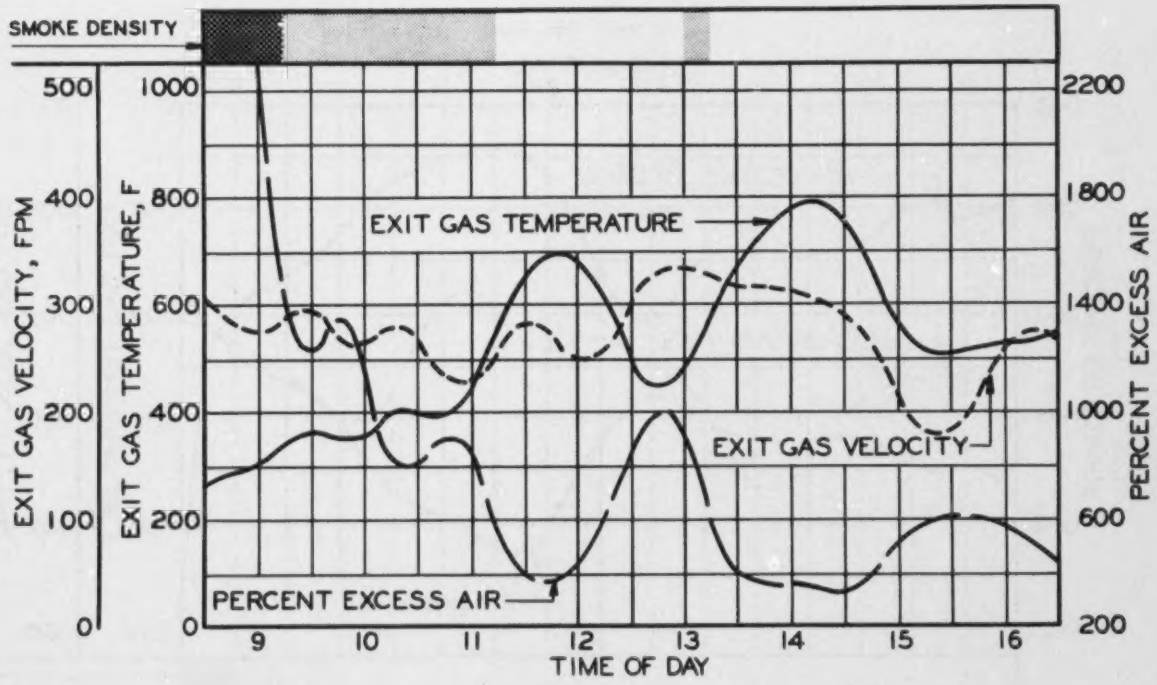


Figure 19. Daily Log, Mill 1, Run 3

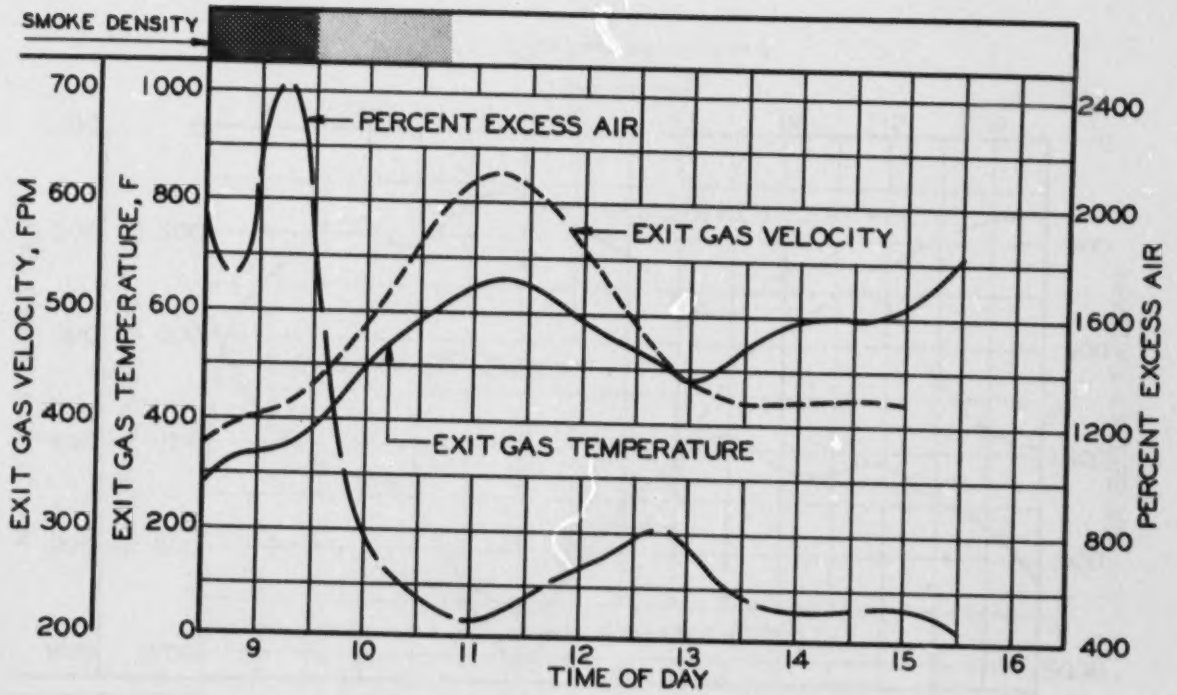


Figure 20. Daily Log, Mill 1, Run 4

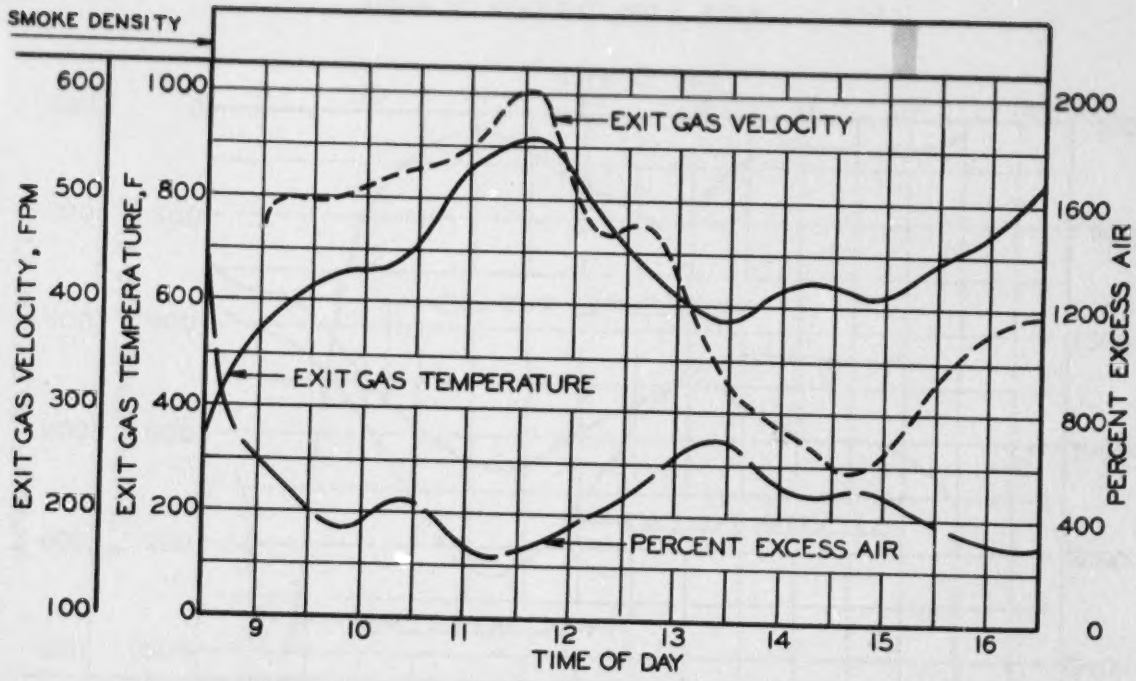


Figure 21. Daily Log, Mill 1, Run 5

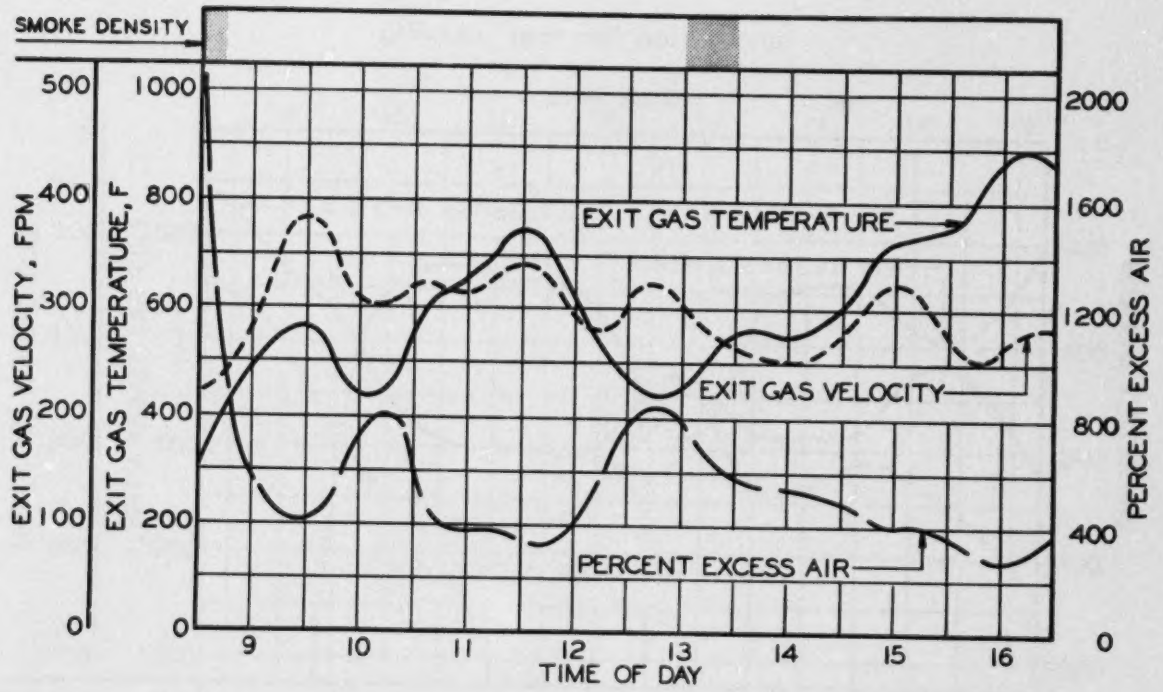


Figure 22. Daily Log, Mill 1, Run 6

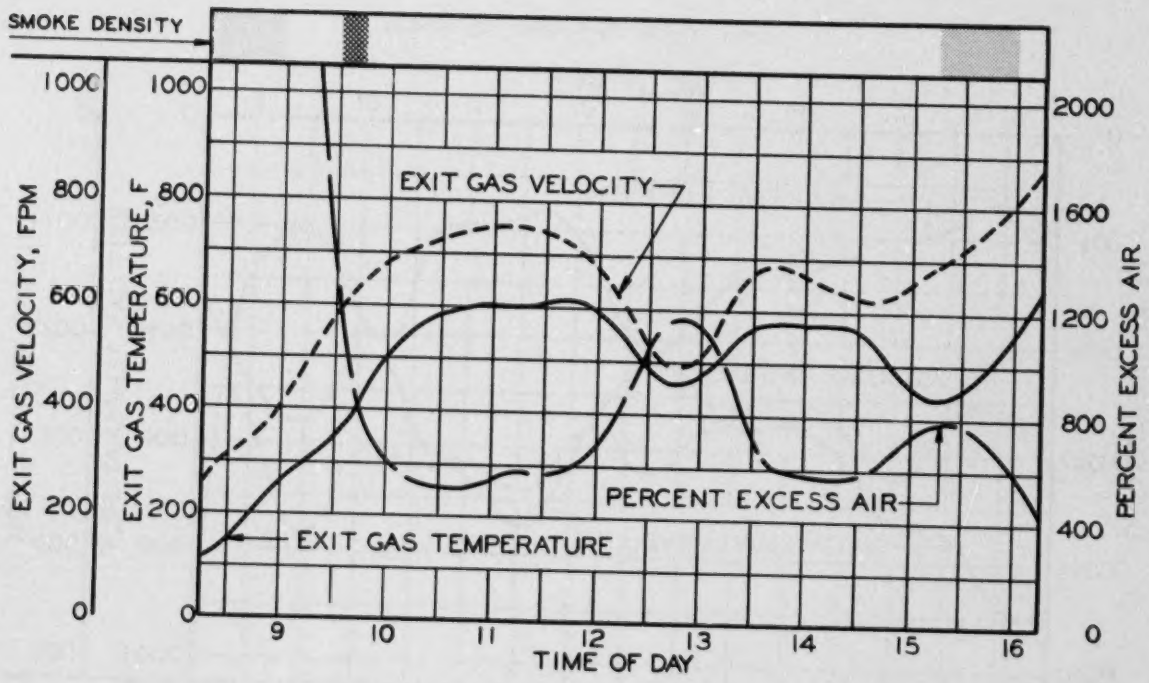


Figure 23. Daily Log, Mill 2, Run 7

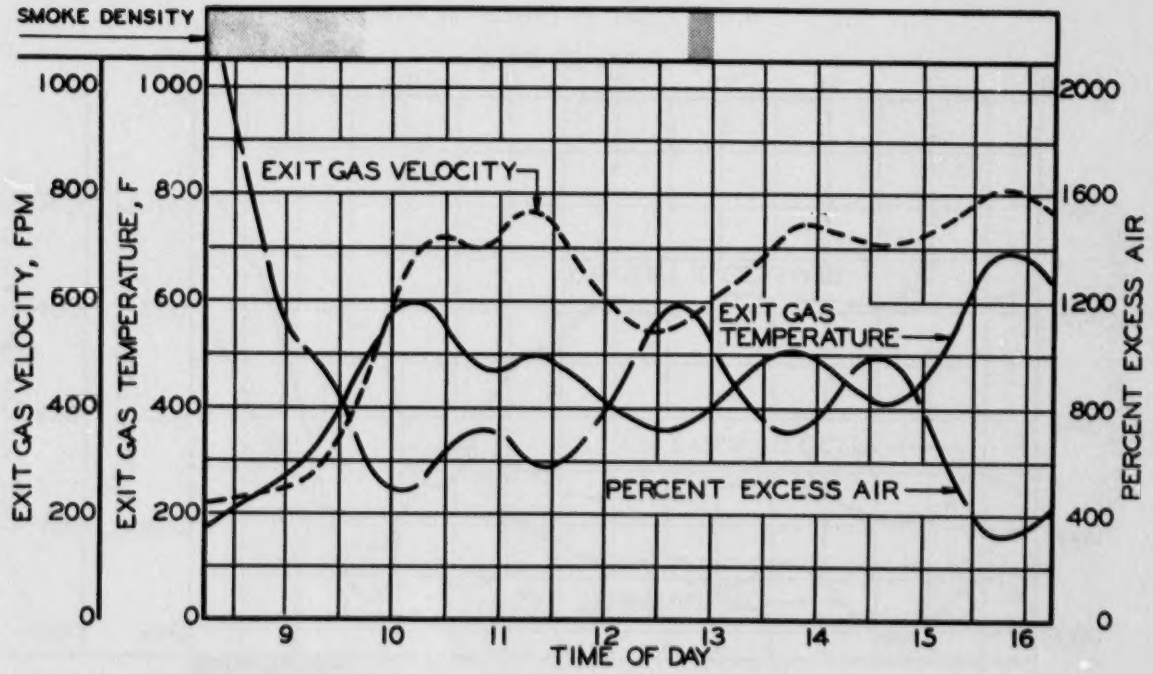


Figure 24. Daily Log, Mill 2, Run 8

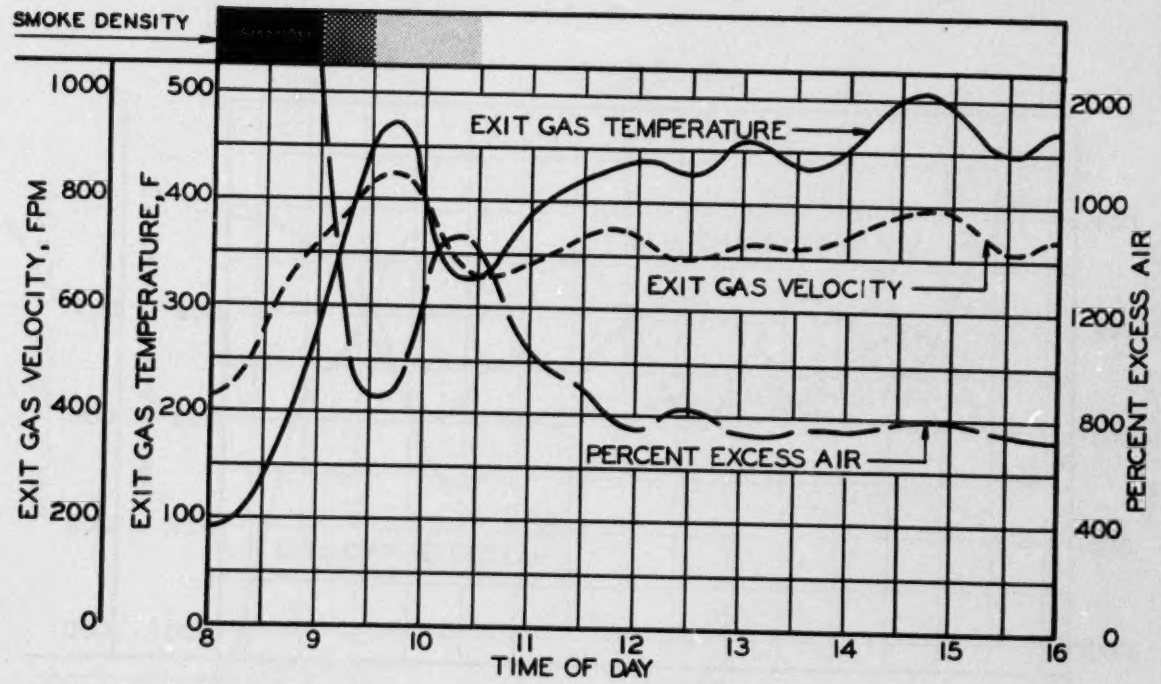


Figure 25. Daily Log, Mill 3, Run 9

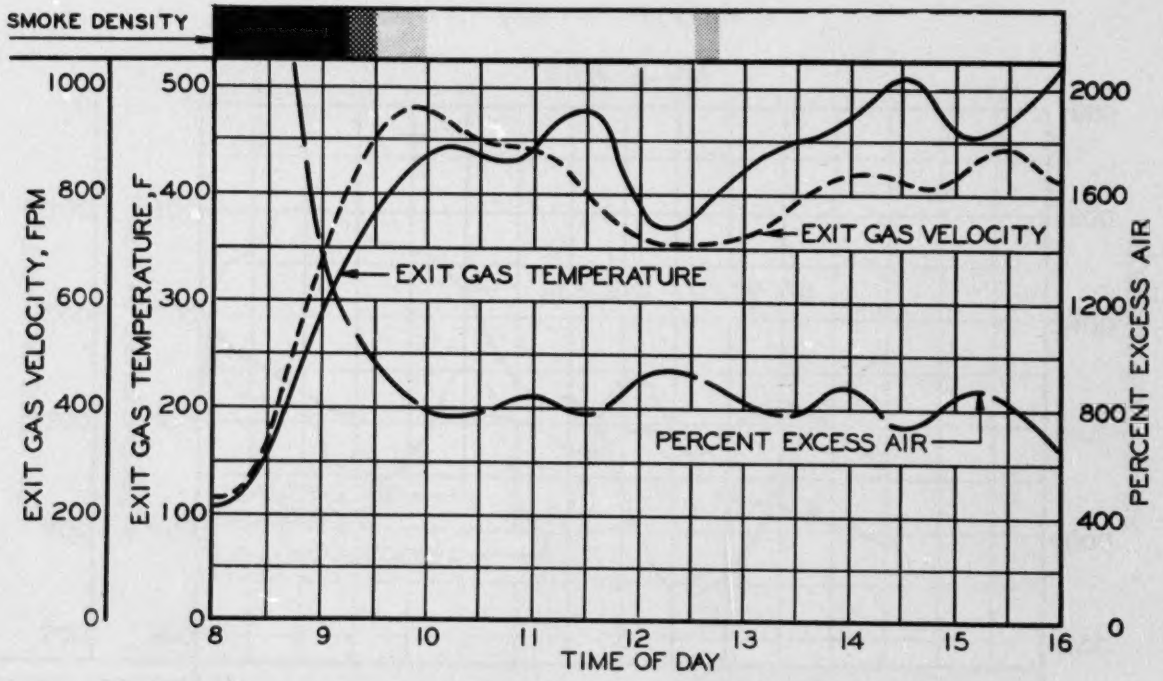


Figure 26. Daily Log, Mill 3, Run 10

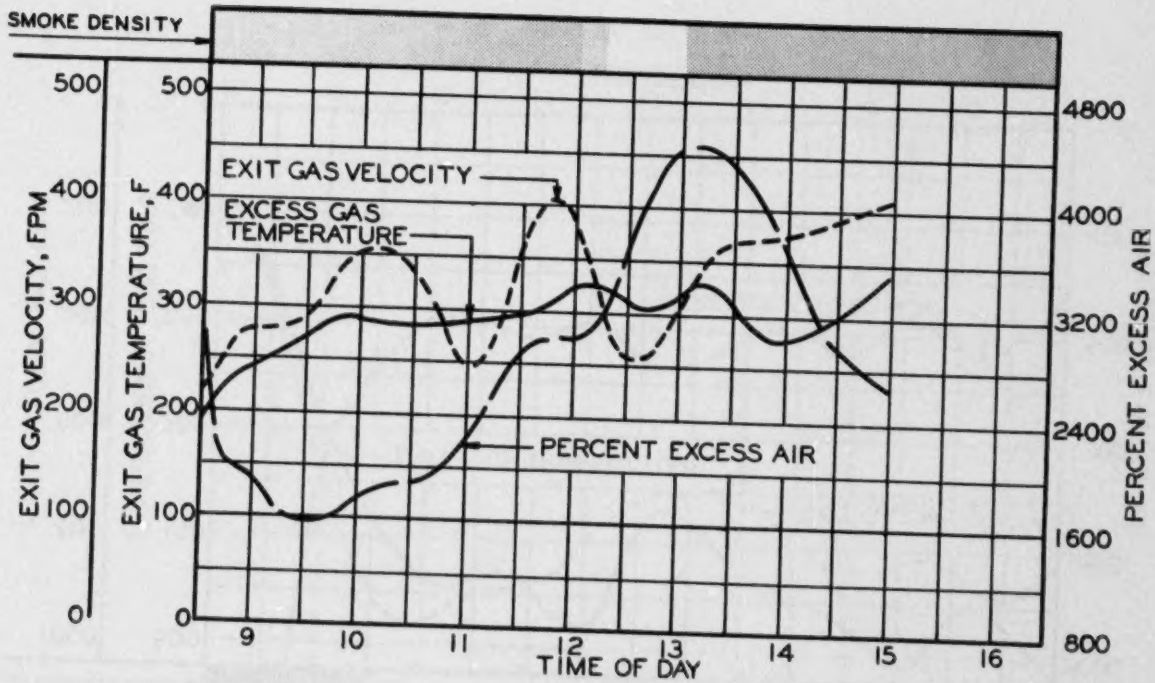


Figure 27. Daily Log, Mill 4, Run 11

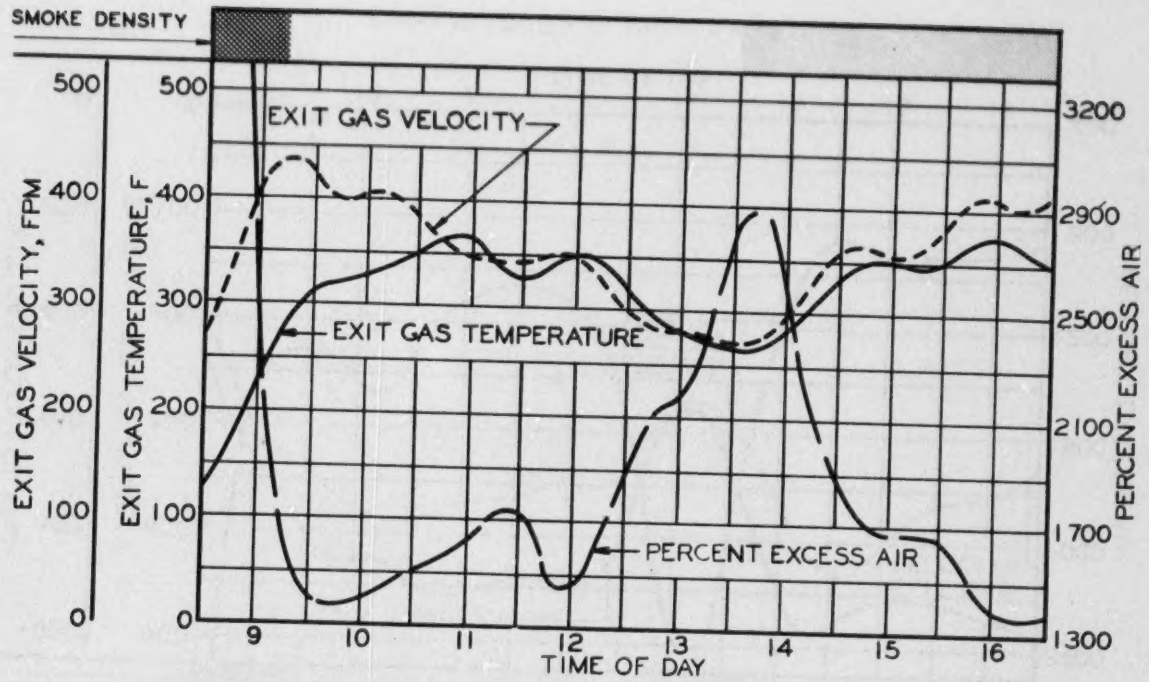


Figure 28. Daily Log, Mill 4, Run 12

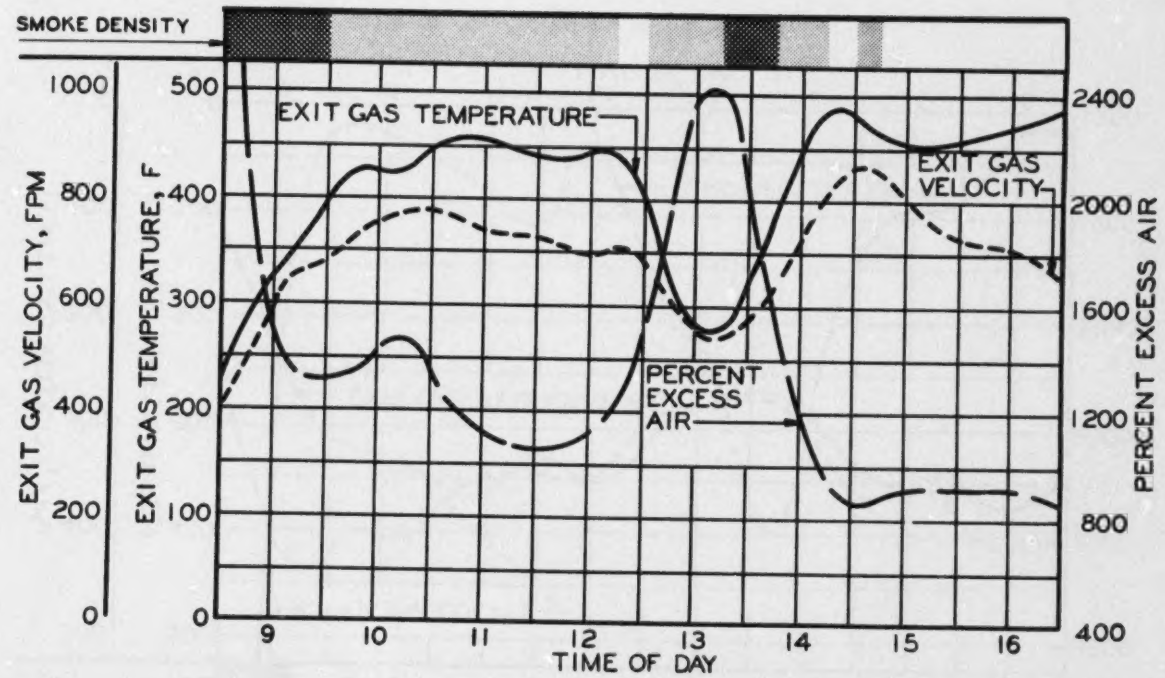


Figure 29. Daily Log, Mill 5, Run 13

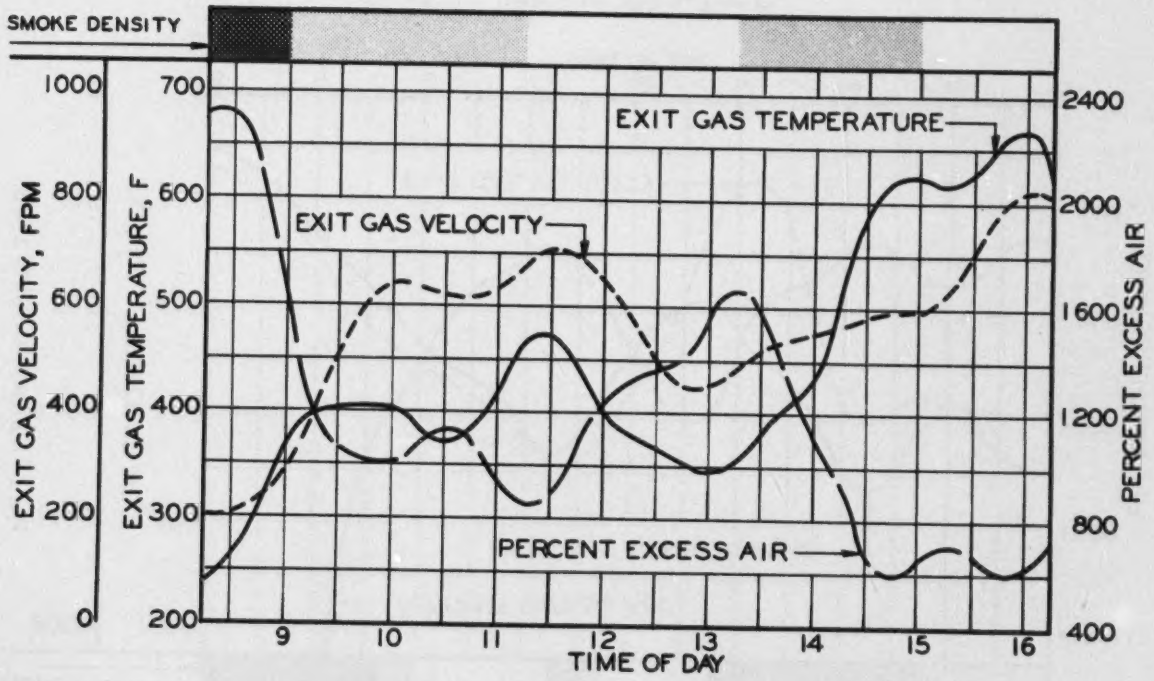


Figure 30. Daily Log, Mill 5, Run 14

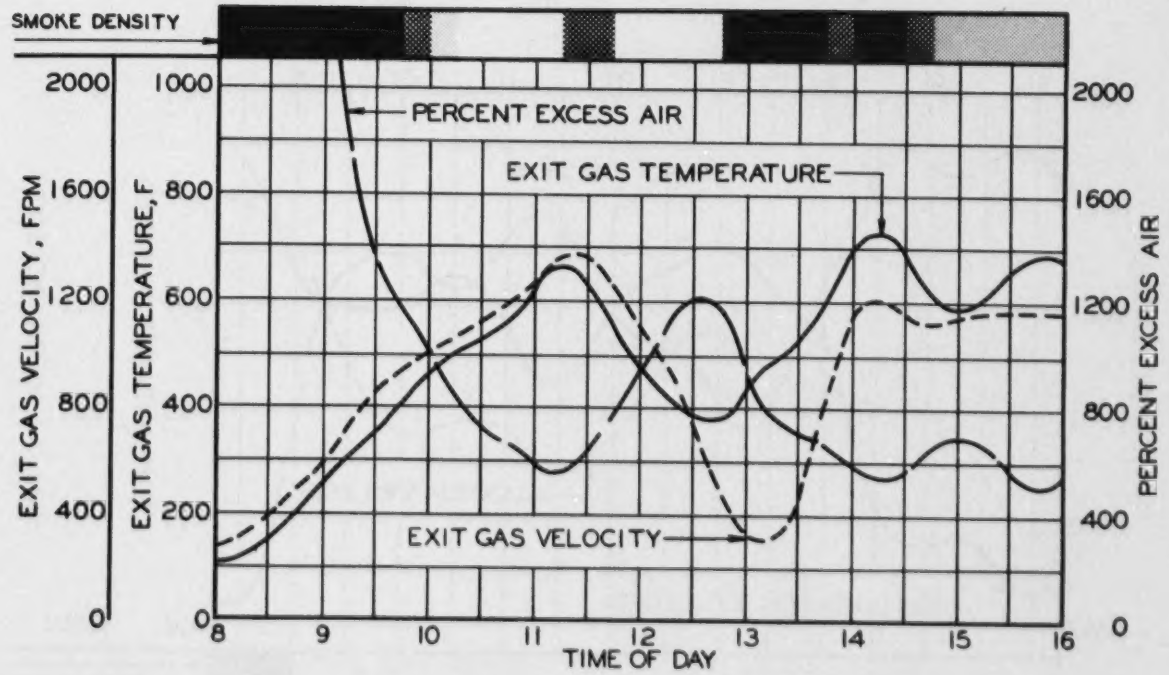


Figure 31. Daily Log, Mill 6, Run 15

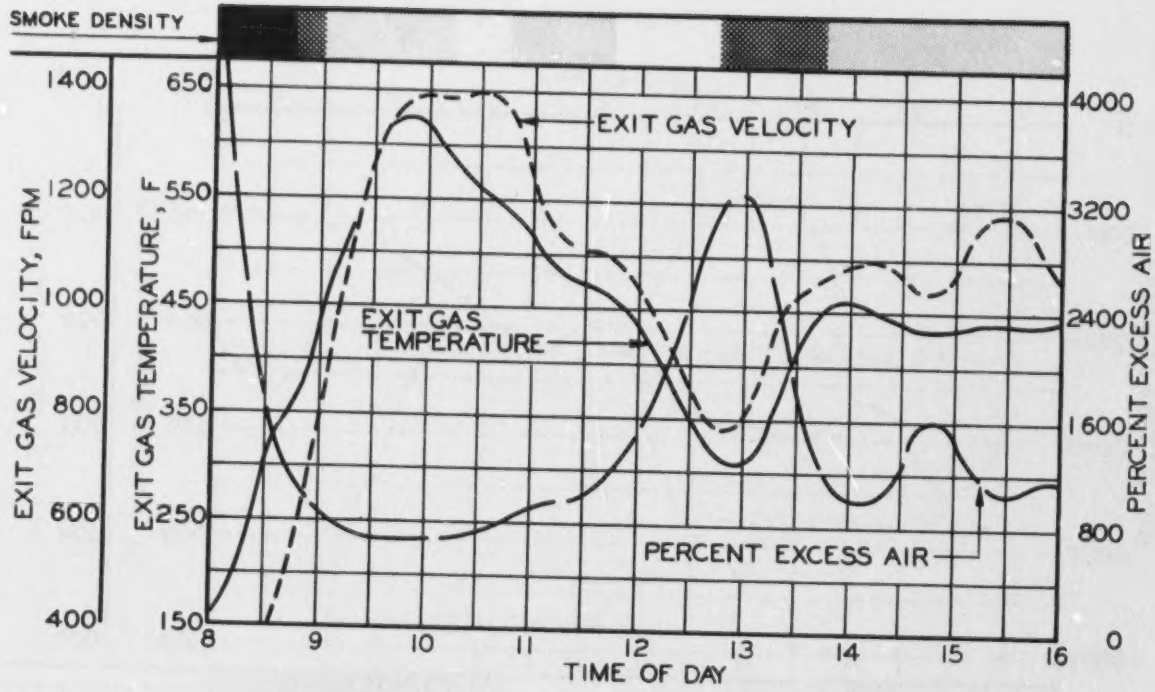


Figure 32. Daily Log, Mill 6, Run 16

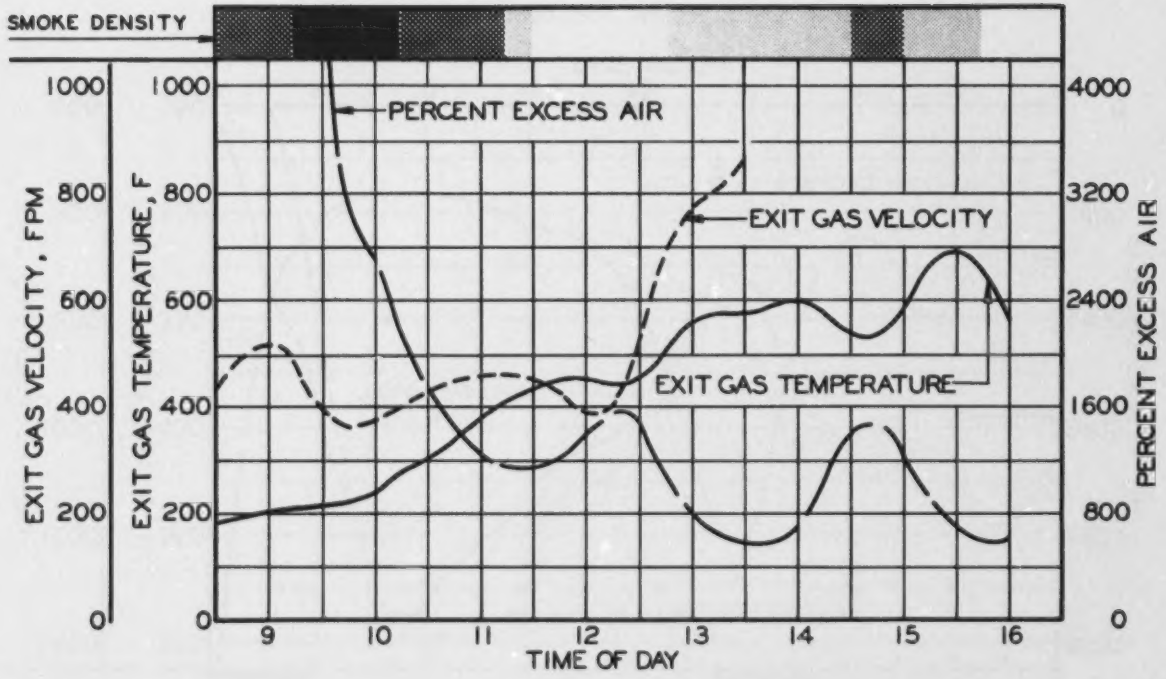


Figure 33. Daily Log, Mill 7, Run 17

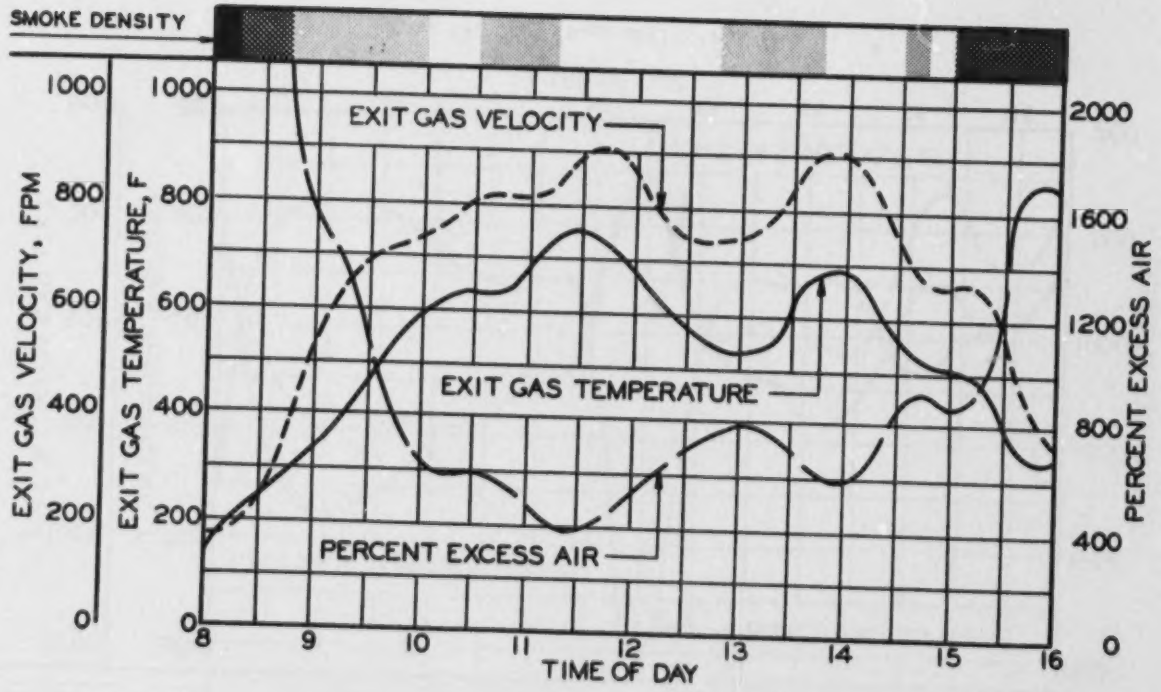


Figure 34. Daily Log, Mill 8, Run 18

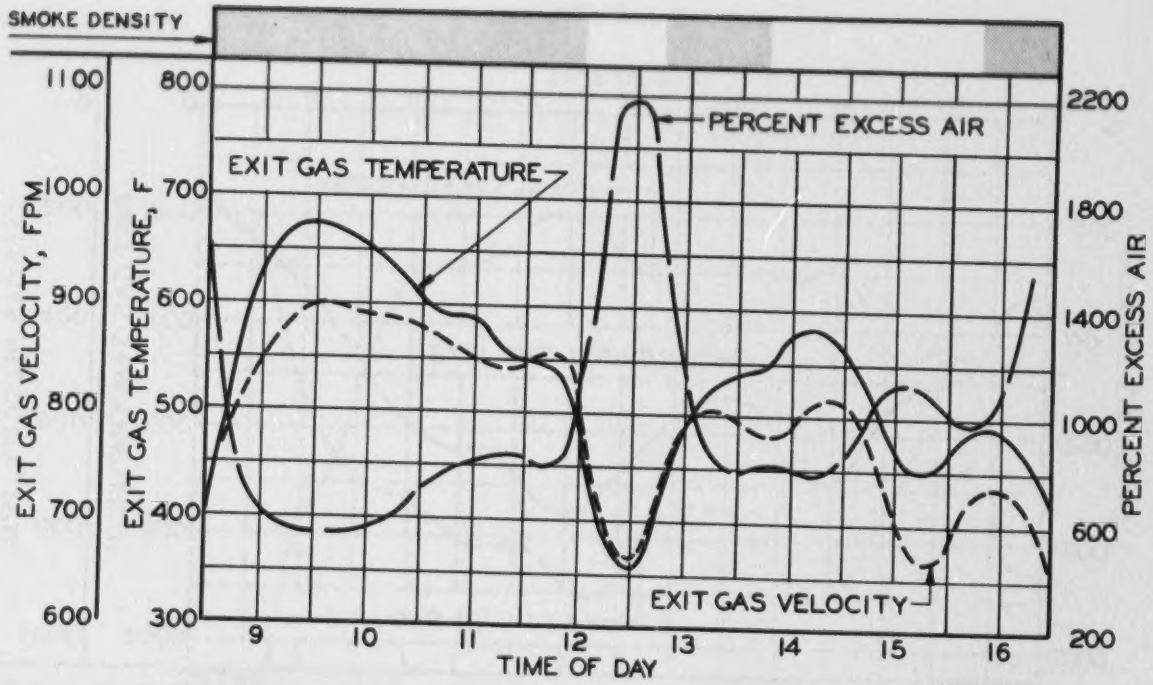


Figure 35. Daily Log, Mill 9, Run 19

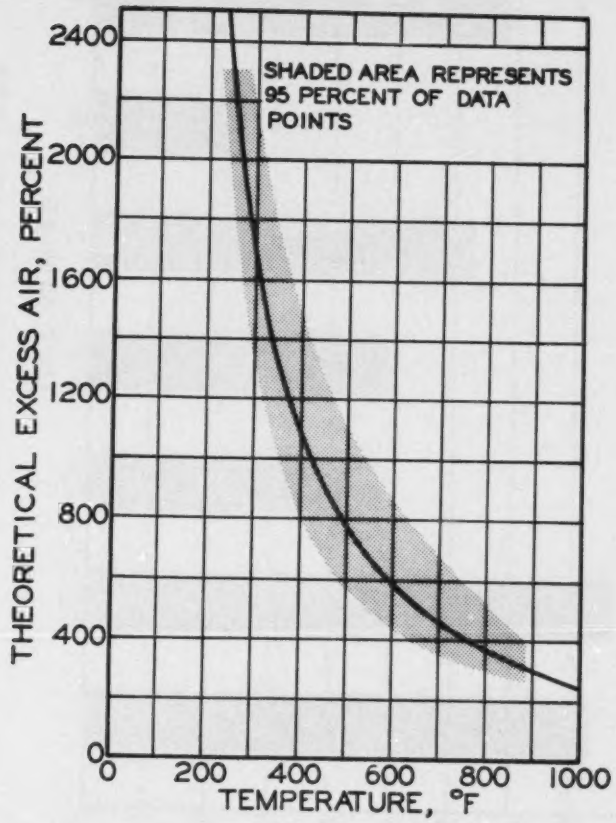


Figure 36. Relation of Excess Air to Exit Gas Temperature

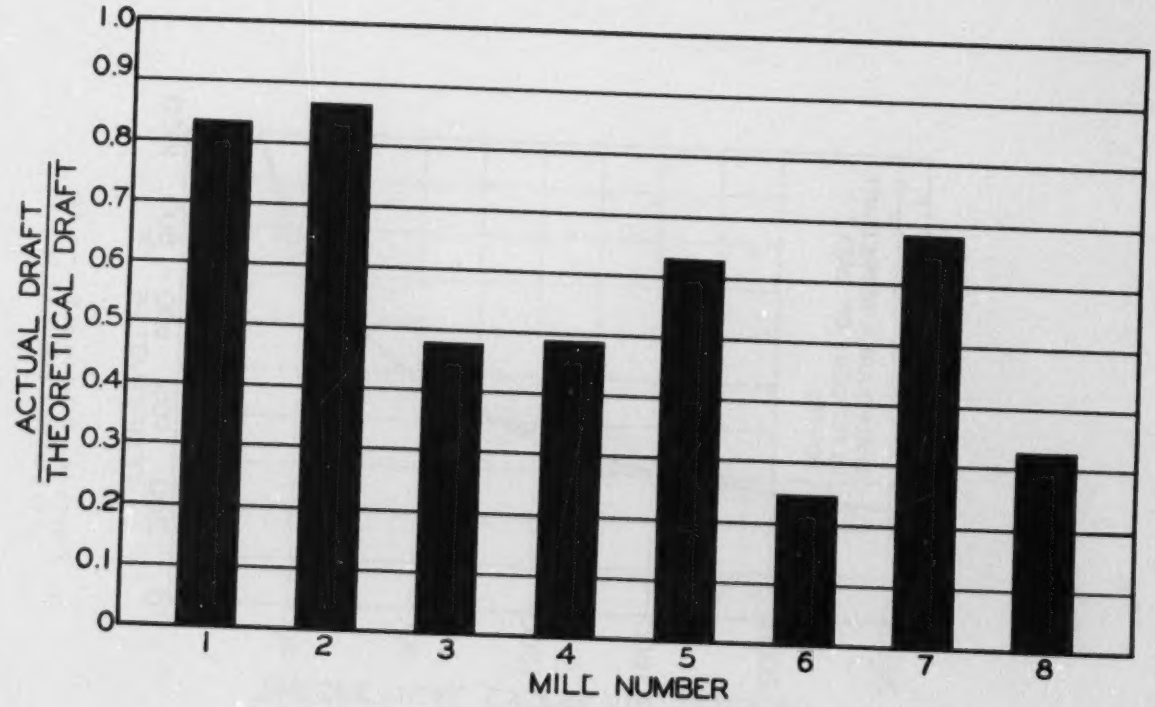


Figure 37. Average Draft Ratio of Burners Tested

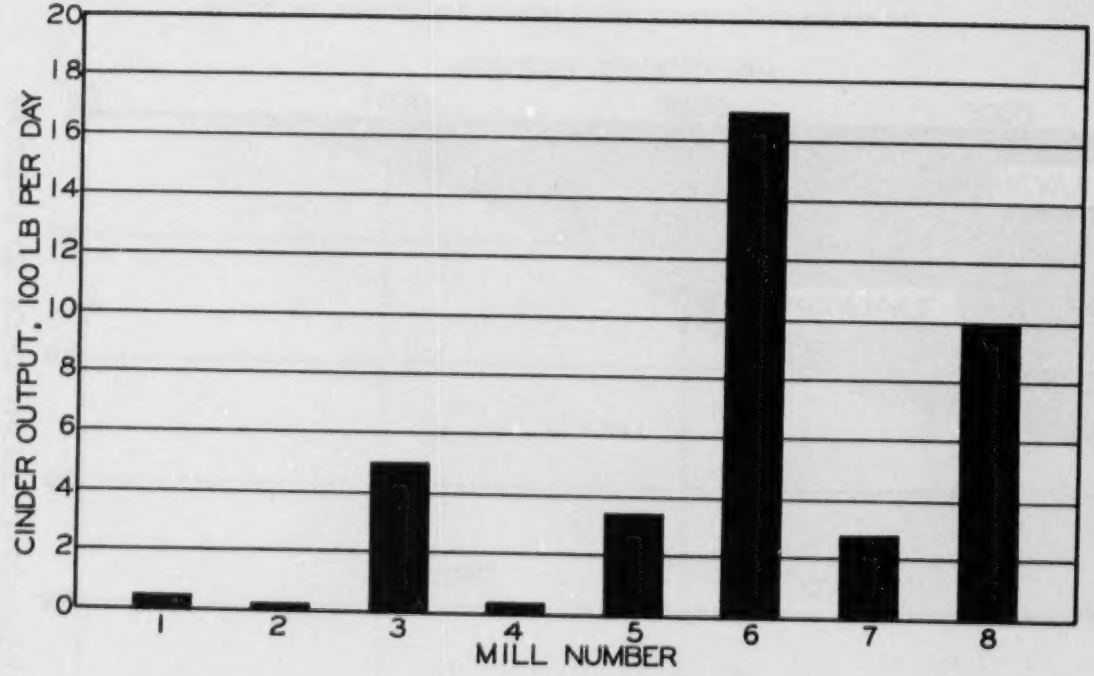


Figure 38. Average Daily Cinder Emission of Burners Tested

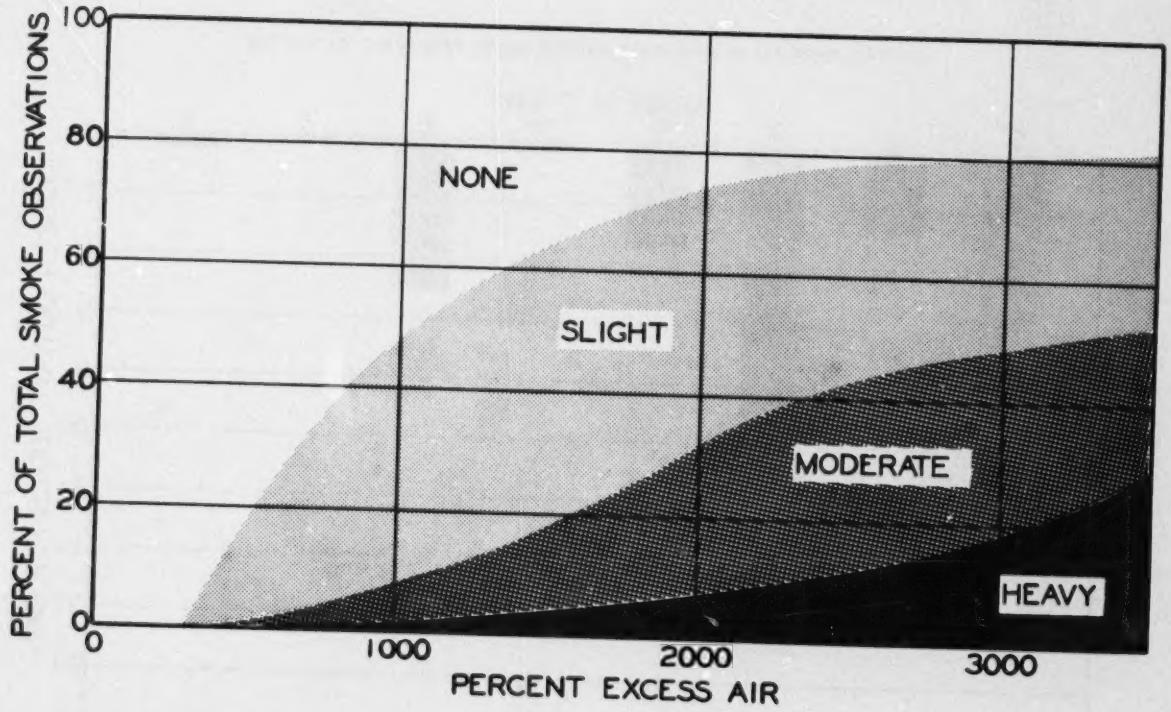


Figure 39. Relationship Between Smoke Condition and Excess Air

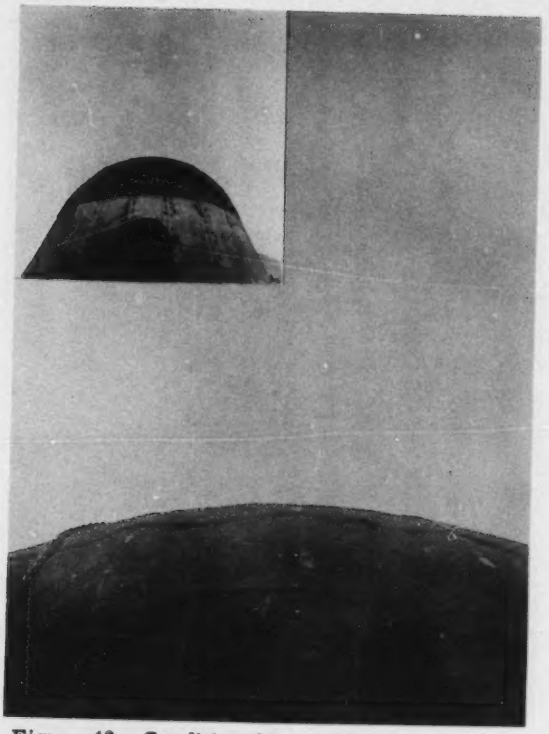


Figure 40. Condition Observed as "No Smoke"

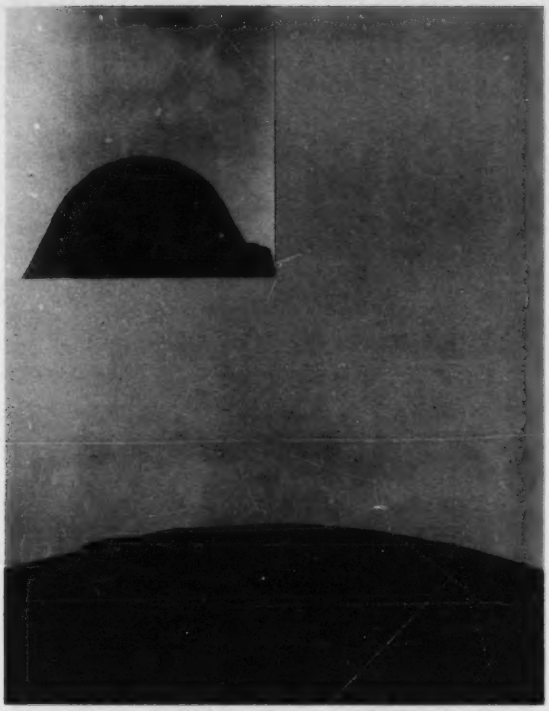


Figure 41. Condition Observed as "Slight Smoke"

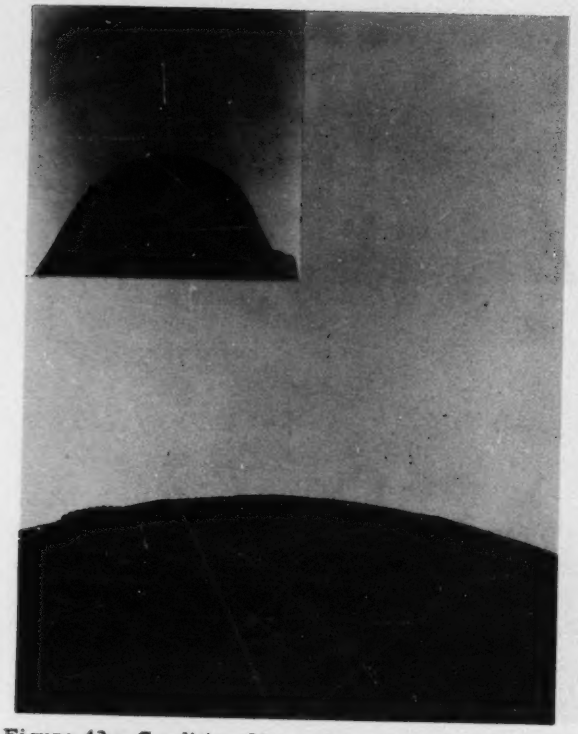


Figure 42. Condition Observed as "Moderate Smoke"

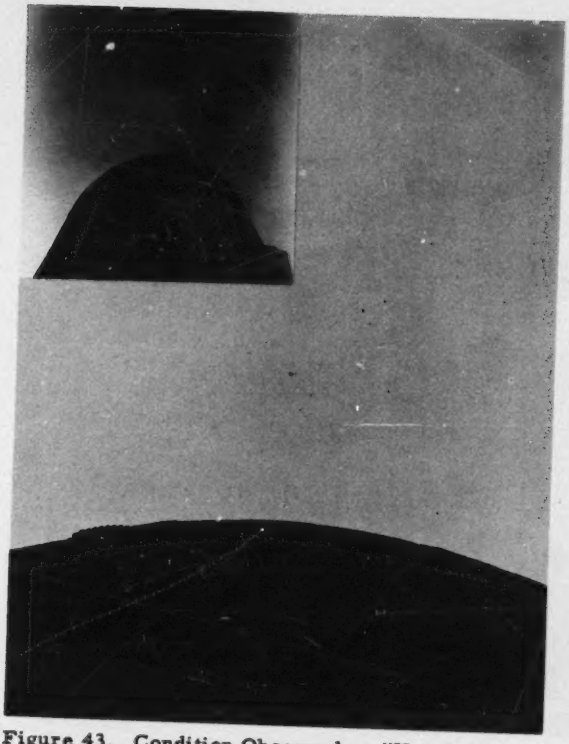


Figure 43. Condition Observed as "Heavy Smoke"

Summary of Test Data From Waste Burners

Mill no.	Run no.	Burner size ft			Burner physical condition	Overfire air inlet method	Type of fuel fired	Fuel rate lb/day	Cinder rate lb/day
		Base	Ht	Top					
1	1	50	48	22	Excellent	Tangential, door open	Shavings, sawdust, slab, trimmings	103,000	141
1	2	50	48	22	"	Run not completed—wind shifted after start			
1	3	50	48	22	"	Tangential, door closed, 1/2 openings	Shavings, sawdust, slab, trimmings	96,000	39
1	4	50	48	22	"	Tangential, door open	Sawdust, slab, trimmings	116,000	20
1	5	50	48	22	"	Tangential, door closed	Shavings, sawdust, slab, trimmings	164,000	15
1	6	50	48	22	"	" " "	" " " "	86,000	3
2	7	35	35	15	"	" " "	Slab, trimmings, some sawdust	83,000	19
2	8	35	35	15	"	" " "	" " " "	99,000	23
3	9	50	48	22	Fair	Nondirectional, door closed	Slab, trimmings, some shavings and sawdust	131,000	390
3	10	50	48	22	"	Nondirectional, door open	Slab, trimmings, some shavings and sawdust	166,000	606
4	11	48	43	22	Excellent	Tangential, door closed	Slab, trimmings, some sawdust	32,000	21
4	12	48	43	22	"	" " "	" " " "	68,000	47
5	13	40	40	20	Fair	Nondirectional, door open	Slab, shavings	166,000	382
5	14	40	40	20	"	Nondirectional, door open	" "	126,000	284
6	15	50	50	24	Poor	Nondirectional, door open	Slab, shavings, some sawdust	269,000	2730
6	16	50	50	24	"	Nondirectional, door open	Slab, some sawdust	290,000	664
7	17	43	40	23	Good	Tangential, door closed	Slab, trimmings, sawdust	69,000	246
7	18	43	40	23	"	" " "	" " "	190,000	291
8	19	50	55	22	Poor	Nondirectional, door closed	Slab, shavings, sawdust, trimmings, edgings	168,000	1002

DISCUSSION OF RESULTS

All the curves (Figures 18 through 35) tend to indicate the same general trends. As excess air decreases, temperature of exhaust gases increases, and smoking decreases.

Another general trend that may be seen by examining the curves is an increase in temperature during startup time in the morning, a decrease during the noon hour and, again, an increase after the noon hour. Excess air, being the reciprocal curve, indicates the opposite. Smoke density is relatively high during start-up periods when temperature is low and excess air is high. Once the burner starts operating well, smoke density decreases due to increase in temperature and decrease in excess air.

The bar graph of the ratio of actual draft to theoretical draft for the various mills is a general indicator of the burner's physical condition. For a burner operating with a large excess of overfire air, this ratio is low. Excess of air may be due to any or all of the following:

1. Door left open while firing.
2. Buckled plates causing air leakage.
3. Leakage around base of burner.
4. Secondary air inlet openings of too much area.
5. Burner too large for fuel load it is handling.

The bar graph of cinder fallout for the various mills indicates the tremendous differences existing between mills. Some are doing an excellent job of disposing of waste in the burners, while others are showering surrounding areas with great quantities of unburned materials.

Photographs correlating smoke to cinders show definite evidence that such a relationship exists. It may be said, then, that a heavily smoking burner also puts out a large quantity of unburned material. These photographs may be verified if the smoke is observed from the base of the burner with a powerful pair of binoculars. Cinders are easily visible when a magnification of 6 or greater is used.

Tabulations in the table on the preceding page give results of all assembled test data. A careful examination of this table shows how fuel rates, burner condition, fuel types, and air inlet methods affect cinder discharge rates.

A complete analysis of each run and burner may be made by studying the organized curves and tabulated data in the results section.

Mill 1

The first run was made at Mill 1, where the burner was in excellent condition. Air was admitted tangentially over the fire to provide combustion air. The door also was open to provide additional overfire air. The forced draft system was plugged and inoperative. The burner was fired with planer shavings, sawdust, slab, and trimmings at a rate of 103,000 pounds a day. Under these conditions a cinder fallout rate of 141 pounds a day was determined. Exit gas temperature was relatively low in the morning, reaching a maximum of 850 degrees F just before the lunch hour. Smoke was moderate at startup, decreasing to slight after 1 hour's operation, and stopping entirely after 2 hours' operation. Exit gas velocity reached a maximum of 740 fpm in the early afternoon.

Run 3 also was made at Mill 1. Inlet air was changed by closing the door to the burner and closing off 5 of the 11 openings. The burner was fired as before, but with only 96,000 pounds of fuel a day. Exit gas was at a low temperature in the early morning, reaching 700 degrees F at lunch time, and a maximum of 780 degrees F in midafternoon. Excess air reached a low of 320 percent at midafternoon. Smoke was moderate for 1-1/2 hours, then slight until 11:15 a.m., with a short period of slight smoke right after the afternoon startup. Exit gas velocity reached a maximum of 330 fpm at the afternoon startup. Cinder fallout was only 39 pounds for the entire day.

Runs 1 and 3 were made under practically identical conditions, except that less air was admitted to the burner during Run 3. This had little effect on temperature or excess air. There probably was incomplete combustion during Run 3 due to less available air, but the greatly reduced gas velocity all but eliminated the fallout of cinders.

Run 4 was made also at Mill 1. For this run all tangential openings were open, as was the door. The burner was fired with

116,000 pounds of fuel a day, but no planer shavings were admitted. Cinder emission was only 20 pounds a day. Gas temperature, excess air, and exit gas velocity were very similar to Run 1, as was smoking. The only significant difference, then, was amount of cinders. This decrease was due to an absence of light fuel particles (planer shavings) being carried out the top of the burner.

Runs 5 and 6 both were made at Mill 1. These were made under identical conditions except that fuel loading for Run 6 was only about half that of Run 5. Air was admitted through all tangential openings and the door remained closed. Cinder fallout rates were 15 and 3 pounds a day, respectively. Gas temperatures were in the same range as when this burner was operated with the door open (Run 1). Excess air was lower, as was gas velocity. This was expected because less air was admitted to the burner. Only slight smoke was evidenced for short periods of time. The important thing was that the cinder fallout rate was dropped from 141 pounds a day (Run 1), to 15 and 3 pounds a day (Runs 5 and 6), by closing the door to give a tighter burner. This burner was doing an excellent job when operating with the door closed, even though the forced draft system was plugged with accumulated ashes and clinkers.

Mill 2

Runs 7 and 8 were made at Mill 2. This was the smallest burner tested. Both runs exhibited the same characteristics: maximum gas temperature about 600 degrees F, minimum excess air about 500 percent, maximum velocity about 780 fpm, and only short periods of slight and moderate smoke. Cinder fallout was low, being 19 and 23 pounds a day, with fuel loadings of 83,000 and 99,000 pounds a day, respectively. No planer shavings were fed to this burner, so discharge of light material was kept to a minimum. This burner did an excellent job in consuming fuel with a minimum or residue discharge.

Mill 3

Mill 3 was the test site for Runs 9 and 10. The burner was old and in a poor state of repair. There was considerable leakage through buckled plates and cracks which caused a high excess air percentage (minimum 750 percent for both days), with accompanying low exit gas temperature (maximum of 510 degrees F for both runs). Maximum gas velocity was 850 fpm the first day when the door was closed, and 950 fpm the second day when the

door was open. Of particular interest was the fact that fallout of unburned material increased from 390 pounds a day to 606 pounds a day when the door was opened. The burner was discharging heavy smoke for about 1-1/2 hours after startup for both days, then moderate and slight smoke, and finally clearing completely after 2-1/2 hours of operation. This indicated the burner did not do a very good job of combustion for the first 2-1/2 hours of mill operation. Poor combustion during startup could be attributed to air leakage through the sides of the burner. The door was opened the second day, but this only aggravated the problem of too much excess air.

Mill 4

Runs 11 and 12 were made at Mill 4. This was a large burner operating with a relatively small fuel input. Characteristics for both runs were the same; long periods of smoking and extremely high percentage of excess air, with accompanying low exit gas temperatures. Exit gas velocity was fairly low—around 400 fpm maximum. At first glance it appeared that cinder output of this burner was fairly low (21 and 47 pounds a day, respectively). Examination of the fuel loading figures, however, indicated this burner was actually doing a poor job of burning the waste. It was smoky and, considering the small quantity of fuel fed to it, discharged a considerable amount of cinders. The burner, in effect, was too large for the refuse it was handling.

Mill 5

Runs 13 and 14 were made at Mill 5. The burner at this mill was relatively small, and was in poor condition as far as air leakage was concerned. To further hinder proper combustion, it was fired at all times with the door open. Both smoke and cinders were discharged in objectionable quantities. The burner was operating with high excess air and low gas temperature, both of which tend to indicate poor combustion. Closing the door would have helped combustion, as this would have decreased excess air and raised gas temperature.

Mill 6

Mill 6 was used for Runs 15 and 16. This was probably the poorest burner tested as far as condition was concerned. Test results further emphasized the poor physical condition. Also, this burner may have been overloaded. Fuel rates were high

(269,000 and 290,000 pounds a day, respectively), with high cinder emission (2730 and 664 pounds a day, respectively). Smoke was in evidence most of the time the burner was operating. Objectionable smoke was exhibited for 4 hours the first day and 2 hours the second day. The reason for the difference between cinder emissions and smoke for the two days becomes apparent from the table on page 57. Note that no planer shavings were fed to the burner during the second day's operation. Also of interest was the extremely slow startup the first day (Run 15). Planer shavings were smothering the fire during this period. Leaving the door open only hindered combustion and added to cinder output.

Mill 7

Runs 17 and 18 at Mill 7 indicated a rather smoky condition for a burner in excellent physical shape. Run 17 showed an extremely slow startup, and excess air was fairly high for both runs. The draft was much lower than it should have been, which may have been due to the burner being situated next to a highway fill. Air currents set up by the location and prevailing winds may have been contributing factors. Also, there may have been air leakage around the base of the burner where there was an opening between the plates and the ground. This opening interfered with tangential motion of air and gases. Considering that no planer shavings were burned, cinder fallout was excessive. This burner was not doing a satisfactory job.

Mill 8

Only one run (19) was made at Mill 8 because of a limitation of time. This burner was in poor physical condition and had an additional set of draft openings about 15 feet from the ground. The test of this burner indicated a generally smoky burner discharging an excessive amount of cinders (1002 pounds a day). Air leakage into the burner again was detrimental to complete combustion.

In general, the curves and table point out the following results:

1. Most satisfactory burners use tangential entry of overfire air, and are fired with the door closed.

2. Physical condition is a good indication of the job the burner will do as far as cinder fallout and smoke are concerned.

3. More cinder fallout may be expected when fuel consists of lighter materials, such as shavings and sawdust.

4. Smoke is more likely to occur during startup when temperatures are low and excess air is high.

5. Burners producing the greatest amounts of unburned material are also the ones that smoke the most.

6. Using the variable of excess air, smoke and cinder fallout may be reasonably well predicted. Figure 39 (page 52) was developed for this purpose from test and computed data.

BIBLIOGRAPHY

1. "All-Steel Refuse Incinerator," Engineering News, Vol. 30, pp. 678-680, April 8, 1915.

2. Annotated Bibliography on Incineration, Carbonization, and Reduction of Garbage, Rubbish, and Sewage Sludge, U.S. Works Progress Administration for N.Y.C., 1939.

3. "Another Angle on the Wood-Waste Problem," Electrical Review and Western Electrician, Vol. 68, No. 11, pp. 463-464, March 11, 1916.

4. Badenhausen, J.P., "Burning Waste Wood in Suspension Without Grates or Dutch Oven," Power Plant Engineering, Vol. 49, pp. 82-84, November 1945.

5. Bastian, H.S., "Hog Fuel Burning and Handling Equipment," Paper Trade Journal, Vol. 99, pp. 29-36, September 27, 1934.

6. Bigelow, C.M., "Controlling Wastes in Woodworking Plants," Industrial Management, Vol. 59, pp. 715-732, August 1920.

7. Blagen, N.J., "Large Mill-Refuse Burner Built of Concrete and Brick," Engineering News, Vol. 76, No. 13, pp. 588-589, September 28, 1916.

8. Bryant, R.C., Lumber, Second Edition. New York: John Wiley and Sons, Inc, 1938.

9. "Burlington Opens Sawmill to Meet Purchasing Problem," Railway Age, Vol. 79, pp. 653-656, October 10, 1925.

10. "Burning Bagasse in the Gilchrist Furnace," Power, Vol. 55, p. 784, May 16, 1922.

11. Calnan, E.J., and J.N. Franklin, "Bark and Refuse Fuel Burning," Pulp and Paper of Canada, Vol. 42, No. 2, pp. 111-116, February 1941.

12. "Carpenter Shop Waste Disposal Plant," Electric Railway Journal, Vol. 69, No. 26, p. 1144, June 25, 1927.

13. Cohen, J.B., "The Effects of Air Pollution by Smoke and Its Prevention," Journal of the Society of the Chemical Industry, Vol. 39, Part 2, pp. 284-285, 1920.

14. "Conditions Under Which Oregon Burns Wood," Electrical World, Vol. 68, pp. 170-173, July 22, 1916.

15. Corbet, D., "Burning Sawmill Refuse," Electrical World, Vol. 76, No. 4, pp. 183-185, July 24, 1920.

16. Corbet, D., "Special Boiler Fuels," Journal of the AIEE, Vol. 39, pp. 715-732, August 1920.

17. Corey, R.C., Some Fundamental Considerations in the Design and Use of Incinerators in Controlling Atmospheric Contamination. New York: Air Pollution Proceedings of the U.S. Technical Conference on Air Pollution, pp. 394-407, 1952.

18. Custodis Chimneys. New York: Alphons Custodis Chimney Construction Company, July 1924.

19. "Design and Operation Features of Refuse Destructors," Engineer and Contractor, Vol. 42, pp. 501-503, November 25, 1914.

20. "Destructor for Wood Waste," Engineering, Vol. 152, pp. 226-227, September 19, 1941.

21. Duncan, F.K., "Measuring Incinerator Performance by Residual Ash Analysis," Engineering News-Record, Vol. 117, pp. 472-473, October 1, 1936.

22. "Dust and Spark Arrestor," Engineering, Vol. 141, pp. 228-229, February 28, 1936.

23. Etherington, H., Modern Fuel Technology, April, 1938.

24. Fahlman, G.A., and N.M. Wood, "Smoke Abatement," The Blueprint, Vol. 7, No. 9, pp. 9-12, September 1949.

25. "Fuels and Firing," Power, Vol. 92, p. 132, July 1948.

26. "Furnace Redesign to Burn Shavings," Power Plant Engineering, Vol. 25, p. 1164, December 1, 1921.

27. "Handling Wood Fuel," Power Plant Engineering, Vol. 25, No. 1, p. 43, January 1, 1921.

28. Harvey, D.F., "Experience Dictates Incinerator Design," Engineering News-Record, Vol. 127, pp. 493-494, October 9, 1941.

29. Hering and Greeley, Collection and Disposal of Municipal Refuse, First Edition. New York: McGraw-Hill Book Co, 1921.

30. Hofft, M.A., "Furnace and Fuel Feeder Design for Burning Refuse," Power, Vol. 72, pp. 980-981, December 6, 1930.

31. Hulsart, C.A., "Bark Burning Furnaces for the Pulp and Paper Industries," Paper Trade Journal, Vol. 111, pp. 65-71, August 29, 1940.

32. "Igloo Incinerator of Troweled Concrete," Popular Mechanics, Vol. 90, No. 2, p. 168, August 1948.

33. "Incinerator for Mill Refuse Made of Brick and Concrete," Engineering News-Record, Vol. 87, No. 18, pp. 727-728, November 3, 1921.

34. Kreisinger, H., "Combustion of Wood Waste Fuels," Mechanical Engineering, Vol. 61, pp. 115-120, February 1939.

35. Lipsett, C.H., Industrial Wastes, First Edition. New York: Atlas Publishing Co, Inc, 1951.

36. "Mammoth Electrical Sawmill Begins Operation," Journal of Electricity, Vol. 53, No. 4, pp. 145-146, August 1924.

37. "Manufacturing Tragedy of Wasted Wood," Manufacturing Industries, Vol. 12, No. 6, pp. 443-446, December 1926.

38. Mawhinney, M.H., Practical Industrial Furnace Design. London: John Wiley and Sons, 1928.

39. "Meldrum Incinerator for Wood Chips," Mechanical Handling, Vol. 24, pp. 356-358, December 1937.

40. Myers, D.M., Economic Combustion of Waste Fuels, Technical Paper No. 279. U.S. Bureau of Mines, November 1922.

41. "New Plant at Clear Lake Washington," American Lumberman, Vol. 2297, pp. 42-43, May 24, 1919.

42. Oakleaf, H.B., Lumber Manufacture in the Douglas Fir Region. Chicago: Commercial Journal Co, Inc, 1920.

43. Panning, H., "Automatic Feeding of Wood Waste Replaces Hand Firing," Power, Vol. 92, pp. 396-398, July 1948.

44. "Pulp Mill Atmospheric Pollution Problems to be Studied," News Items, Vol. 1, No. 5, p. 1, June 1957.

45. "Sawdust and Chippings Collection," Institution of Heating and Ventilating Engineers Journal, Vol. 9, pp. 211-217, October 1941.

46. "Sawdust and Shavings Collecting Plant," Engineering, Vol. 114, p. 596, November 10, 1922.

47. "Scrapyards Cut Down Smoke With Incinerator Controls," Iron Age, Vol. 179, No. 19, pp. 114-116, May 9, 1957.

48. Telford, C.J., Small-Mill Machinist. Madison, Wisconsin: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 1936.

49. Uhde, D., "Die Mullverbrennung Nach Dem Kriege," Verein Deutscher Ingenieure-Zeitschrift, Vol. 71, Part 2, pp. 1257-1262, September 3, 1927.

50. Very, E.D., "Basic Principles of Incineration," Engineering News-Record, Vol. 116, pp. 687-690, May 14, 1936.

51. Watson, G., "The Future of Refuse Disposal," Engineering, Vol. 142, p. 219, August 28, 1936.

52. Webber, L.E., "Furnaces for Wood Burning," Power, Vol. 85, Part 2, pp. 471-473, July 1941.

53. "What Design of Furnace is Best for Burning Mill Refuse?" Power, Vol. 58, pp. 29, 67, 107-108, July 3-17, 1923.

54. "Wood Waste Destructor," The Engineer, Vol. 170, p. 220, October 4, 1940.

55. "Wood Waste Disposal," Electrician, Vol. 125, p. 164, August 2, 1940.

PART II. ECONOMICS OF WOOD RESIDUE UTILIZATION

INTRODUCTION

Unfortunately, the term "wastes" often bears the connotation of negligence and squandering. For future reference in this report, therefore, the word will mean material not used, but which could have been utilized under present market conditions and technology. Material that cannot be used now but, with technological advances may be used in the future, is called "residue."

With the above objective in mind, the following section may appear as an easy solution to the burner problem. The lumber industry only wishes this was true. At present, however, cost of complete elimination of the burner is associated with the cost of a well integrated forest products company.

Just where does this leave the small operator who has his eye on the future? Should he repair his present burner? Based on the previous section, the answer is a definite "Yes." Should he think about converting material now going into the burner into usable raw material or products? Again the answer is an emphatic "Yes," if it is economically feasible under existing market conditions.

If conversion is feasible, it would be wiser for the sawmill owner to contemplate expansion on products already tried and accepted rather than to spend time and money on speculative items. This does not mean that small mills must leave all product development or utilization ideas to large companies, as there are several lumber associations and public research agencies (see appendix for listing) that offer services to small companies that do not have research facilities. In addition, there are also private research organizations.

If the seed of better utilization can be sown and helped to germinate by showing different uses and possible cost ranges of plant additions, the purpose of this report will have been achieved.

The mill owner can gain in the following ways:

1. By converting into profits material formerly burned.

2. By having increased diversification of products, and

being able to cope with economic fluctuations.

3. By creating favorable public opinion through efficient burner operation and raw material utilization.

Basic limits of this report are as follows:

1. Only mills cutting 80,000 fbm a day or less are considered, because this group represents well over half the mills in Oregon.

2. Raw material wastes or produced items to be sold at the mill, or sold to a remanufacturing company. Selling and management costs are not included in this report because of the complexity of a sales organization.

3. All utilization equipment is considered as newly purchased. This may serve as an incentive for the mill owner to consider used equipment, and thus save money.

4. It has been assumed that raw material essential for a process has been separated from other wastes.

QUANTITY OF MATERIAL AVAILABLE

About 30 to 50 percent of every log run through a sawmill becomes waste and residue. Utilization of this material is determined by its characteristics. Classification and definition of this sawmill refuse are necessary for use.

There are essentially six types of leftover materials produced in the breakdown of a log into lumber. These include slabs, edgings, trim, shavings, sawdust, and bark. Slabs are those pieces removed by the head-rig which have one sawn surface, with the remaining surfaces being unsawn. Edgings are produced at the edger and may be defined as pieces having two or more sawn surfaces, with the remaining surface or surfaces being unsawn. When a piece of lumber is reduced to a specified length in regard to grade, the portion removed is trim. That portion of the log removed as kerf during sawing operations is sawdust. Shavings are thin pieces of wood removed from the surface of lumber during planing. Bark is the protective outer layer of the log.

When relating these residues to their possibles uses, it is

common practice to include slabs, edgings, and trim into the single category of coarse residue. Depending on method of operation, bark may or may not occur in conjunction with other residues, but for the purpose of this report the volume of all other material is considered free of bark.

Quantity of waste and residue produced in sawmill operations in the state of Oregon in 1953 is shown in Figure 44.

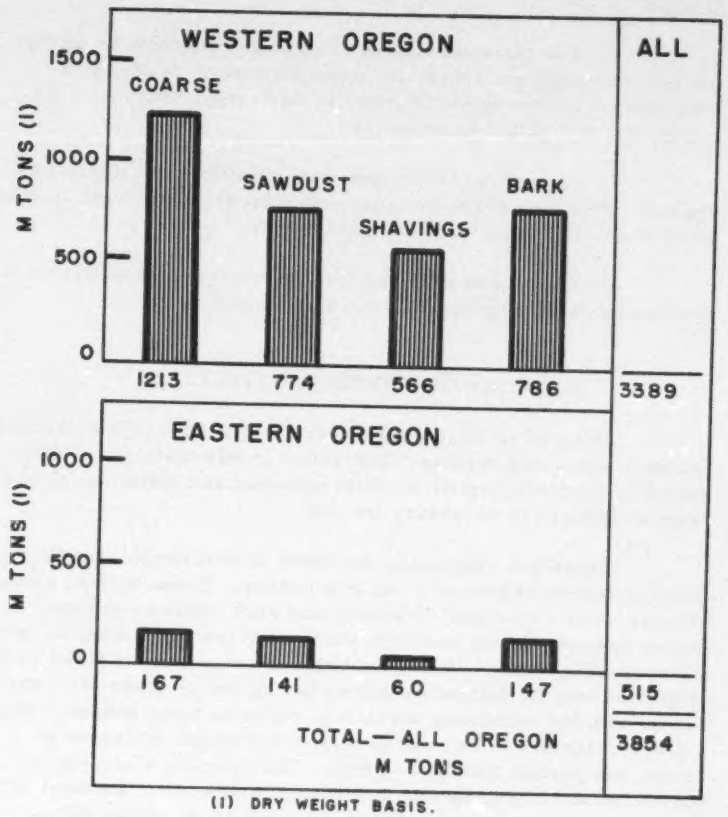


Figure 44. Sawmill Wastes and Residues (7)

Amount of refuse produced in any operation depends on species, defects, sawing practices, and log size. These variables

are responsible for the differences in residue volumes between eastern and western Oregon. Figure 45 illustrates the averages for each region. The individual mill owner may use these values as an approximation of his own waste and residue production, provided he is following general practices of that region.

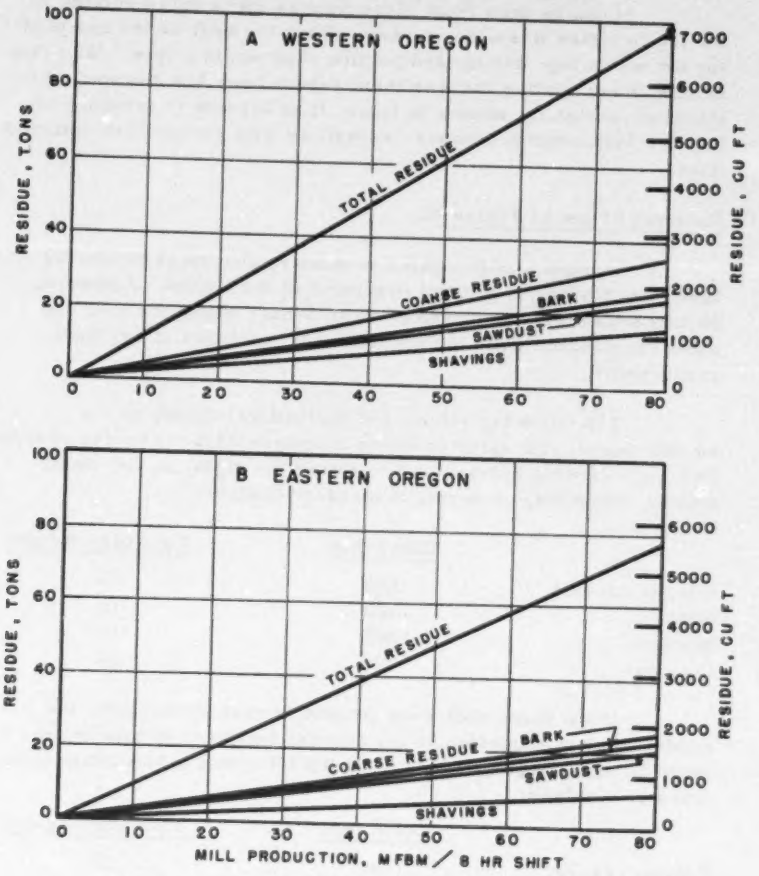


Figure 45. Residue Production by Mill Size (7)

The volume of this production, shown in cubic feet and tons, was derived by using conversion factors presented in Oregon Mill Residues in 1953 (7), which were compared with conversion

factors used in similar reports (4). To estimate the quantity produced, lumber production in thousands of board feet was multiplied by these conversion factors for each residue class. These are the values plotted along the vertical axes of Figure 45.

It can be seen from these figures that a large volume of the log is either waste or residue. Since the mill owner has paid for the whole log, any unused portion represents a loss. Why then should he not realize the maximum return from his invested dollar. He must realize it, sooner or later, if he intends to remain competitive with other producers, as well as with competitive commodities.

Example of use of Figure 45

Suppose a mill located in western Oregon is producing lumber according to general practices of the region. Assuming 60,000 board feet are produced in an 8-hour shift, the mill can expect to produce daily the approximate quantities of residues shown below.

The following values are derived by reading up the 60,000 board- foot value to where it intersects a particular residue line and following horizontally to either the right- or left-hand margin (depending upon unit of measure desired):

	Cubic feet	Tons (dry weight)
Coarse residue	1800	26
Bark	1300	19
Sawdust	1200	17
Shavings	900	12

If the same mill were located in eastern Oregon, and cutting lumber according to the general practices of that region, it could be expected to produce daily the following approximate quantities of residues:

	Cubic feet	Tons (dry weight)
Coarse residue	1300	19
Bark	1200	17
Sawdust	1100	15
Shavings	550	7

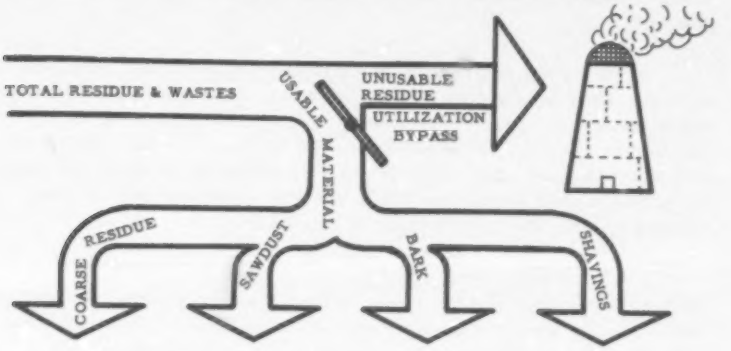
It should be understood that these are only rough averages dependent upon mill practices, and a survey of actual residues

produced by the individual mill would be required to obtain true values. Log diameter and defects are two of the important factors that could give a mill a considerable variation from the average.

POSSIBLE USES AND ECONOMIC CONSIDERATIONS

Possible uses

Just what can the sawmill operator do with leftover material if he does not burn it? There are now many existing uses that have proved profitable under favorable market conditions. There are also many potential uses under consideration, development, or pilot plant operation by public and private research agencies. A partial list of these is shown in Figure 46.



Fuelwood	Fuel	Hog Fuel	Agriculture
Hog fuel	Agriculture	Agriculture	Flakeboard
Chips	Briquets	Extenders	Wood Flour
Lath	Wood Flour	Fillers	Briquets
Cut-stock	Sweeping Compounds	Oil Drilling Compound	Chemical Extraction*
Edge- & End-glued stock	Sawdust-cement concrete*	Wax*	Insulation*
Charcoal	Pulp*	Cork*	
Chemical extraction*	Extractives*		
	Insulation*		
	Ethyl alcohol*		
	Molasses*		

*Either limited at present or in need of technological advancement to become economical.

Figure 46. Uses for Material Now Burned

These uses represent major utilization methods. It can be stated strongly that there are many others (16), such as broom-handle stock, agricultural litter, and grain doors—all of which provide excellent opportunities in certain localities.

Economic considerations

Although there are many possible ways of utilizing wood wastes, the mill owner usually will find that some of the practical methods open to him have economic limits. A serious study of these limiting factors is necessary before further consideration is given to production of a particular product.

Some of the important questions a sawmill owner will want to ask himself are listed below, together with brief explanations of each (15).

1. What is present mill production per shift? Unless average daily production of mill is known, it is impossible to estimate the amount of residue available for production of a useful by-product. The mill owner who does not know his actual production averages can possibly make the best investment in time and money by having a competent man study the mill to determine residue volume in relation to variables of production.

2. What is degree of permanency of mill? Degree of permanency should be the basis of long-range planning. Some by-products are saleable only if they can be supplied at a continuous rate throughout the year, while others are in demand only on a seasonal basis. The owner should think carefully about an expansion program if the mill plans to be in operation for only a few years.

3. What is available timber source? Source of the company's timber may determine the degree of permanency of the mill, or its policy toward future growth. The company owning some timber is in a much different position than one that must purchase logs on the open market. Both can strive for better utilization if they can count upon a continuing log supply.

4. What is average log size cut and percent defect? The average size of log cut will determine to a large degree the amount of leftover material produced during sawing. In proportion to the amount of lumber cut, smaller logs, in general, produce more coarse residue and bark than do large logs. Some other

factors which affect amount of residue produced are:

a) Size of lumber cut. (Large sizes produce little sawdust.)

b) Degree of finishing. (Planer shavings vary directly with proportion of lumber surfaced.)

c) Amount of lumber dried. (Drying decreases planer shavings to some degree due to shrinkage, and increases amount of trim.)

5. What is quantity of needed residue? Amount of residue of a given type that will be available for production can be estimated roughly by use of Figure 45. Before any engineering is done to start production of an item, a survey of the quantity of the required type of residue should be conducted over a sufficient period of time to give the actual average that can be expected.

6. What is available market and average selling price? The importance of determining demand for a product on an annual basis cannot be overemphasized. Such information should include the amount being supplied by other producers, distance and transportation costs between producer and outlet, and current or probable selling price or wholesaler's contract price for the item.

7. What personnel additions will be necessary? Changes in physical plant and personnel necessary to accomplish the expansion program must be considered. It may be possible to use present plant help or part-time workers.

8. What types of equipment will be needed? Equipment to produce the product should be large enough for present residue and production capacity, and to take care of expected mill expansion.

9. How much capital is available for expansion? Because expenses will accumulate before the product can be produced for sale, a certain amount of working capital is necessary to sustain planning and construction stages of the operation. This necessity limits the size of the expansion program which can be attempted.

10. What degree of utilization of residue is now practiced? One major consideration for any operator is the degree of utilization being practiced in the existing plant. A careful study of

present methods of operation may show ways of reducing refuse produced and of obtaining quality control over the principal manufactured item. If the plant already is producing one or more by-products from mill wastes, what will be the effect upon these by-products?

With information from the foregoing questions, and with some definite uses in mind, the mill owner can now take careful stock of his present situation. He should narrow his selection to a few interesting possibilities that appear feasible for his operation.

In the next section, a close look will be taken at actual production methods and average costs. This procedure may lead to a realistic and profitable choice.

The keynote to the success of any expansion program is careful planning.

ESTIMATING COSTS OF PRODUCTION

Most forms, explanations, and examples provided in this section are given for the purpose of "quick figuring." They are familiar "rules of thumb" so often referred to in trade literature.

The sawmill owner can now take ideas in which he is interested, add his previous economic findings, and fill out the appropriate forms to see whether or not he can justify an improvement in wood utilization.

Remember that if one idea looks promising, there also may be others and, if so, the mill owner should contact prospective buyers of the products, transportation agents (if shipping is necessary), and others with similar operations.

The mill owner should conduct an accurate cost estimation before making any final decisions (6).

Range of investments

Figures 47 and 48 graphically illustrate the components which comprise several typical investments. Prices of individual pieces of equipment or installations represent delivered, installed cost at Eugene or Klamath Falls, Oregon. They are based on estimates given by several machine manufacturers or an appraisal company.

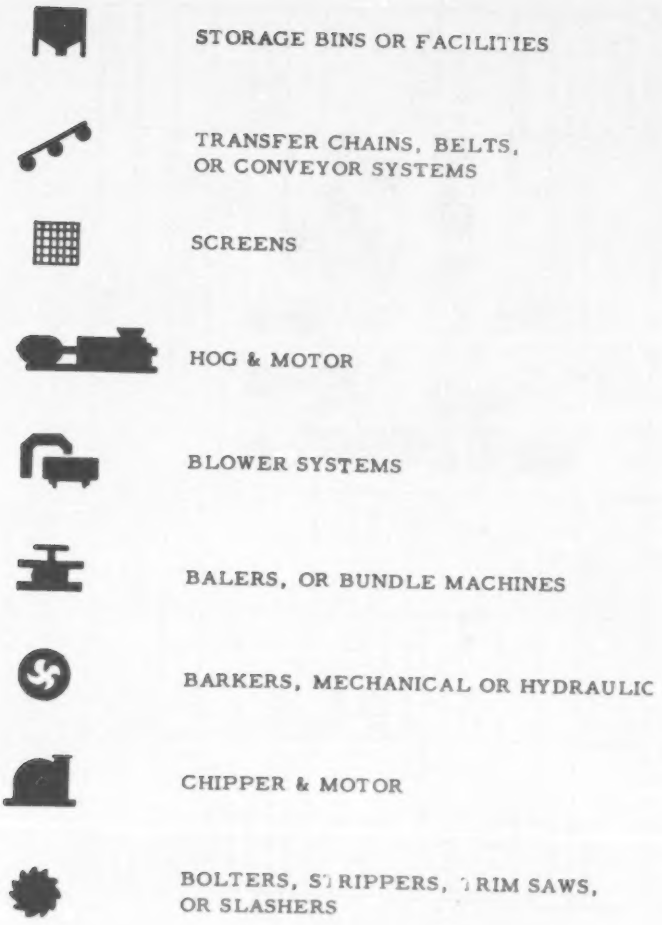
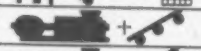
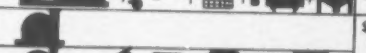
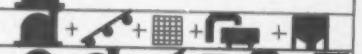


Figure 47. Legend for Range of Investment Sheet

Operation	Variations of operation	Range of investments (installed)	Combinations of equipment	Average selling price of products*
Fuelwood		$0-5,000	Slasher--4-saw unit	$4.00/cord
Fuel, Sawdust		$500-4,000		$0.60/unit
Hogfuel	Hog only	$5,500-9,000		$0.50/unit
	Installation	$12,000-20,000		
Chips	Chipper only	$6,500-20,000		$7.00/unit (bone-dry)
	Chipper installation	$30,000-80,000		
	Chipper & barker	$40,000-200,000		
Agricultural uses	Numerous possible	$500-3,000		**
Square stock	"	$10,000-30,000		Depends on size & shape of items
Finger jointing or end matching	"	$60,000+	End matchers+Conveyors+Joint assembler	"
Edge or end glued	"	$1,450+	Mills with drying facilities should consider.	"
Cut stock	"	No estimates	" " " " " " "	"
Flakers	--	"	Flaking machine	Not known

* Fob mill.

** Sawdust, $0.50-$17 a unit (high range is for well-rotted specialty material); Shavings, $12-$30 a ton, or $0.45-$1.10 a bale.

+ Represents one cost estimate only.

Figure 48. Range of Investment Sheet

The price range signifies the difference between similar pieces of machinery (chipper versus chipper), or groups of equipment (compatible machinery in output which forms a method, system, or process). Deviations, if any, from these price ranges may be caused by abnormal installation costs, high delivery rates, or competition between machinery manufacturers.

Use of estimating sheets

The following forms are offered as quick methods of estimating possibilities of some utilization methods. Two separate methods of estimation are shown. One is a brief rule of thumb method suitable for preliminary investigation of various types of operations, and the other is a somewhat closer scrutiny of the possibilities of an operation if it shows promise by the first method.

It should be pointed out that these are merely methods of estimation to determine if a process might be practical. They are not to be substituted for final engineering data, nor are they a guarantee that the operation will be a success even if the estimate shows the operation to be practical.

The rule of thumb method requires that approximate cost of all equipment, including installation, be known in addition to expected volume of production. Total fixed costs are determined by taking a percentage (20% for a 10-year amortization plan, or 30% for a 5-year amortization plan) of the total physical plant cost.

This calculation is based on the assumption that total physical plant cost will be twice the installed equipment cost if the operation is housed in an entirely new building with all new equipment. For an operation that can be housed entirely within the existing plant, it is believed this factor of two times the installed equipment cost may be too high. This flexibility allows the owner to make an adjustment in the factor, depending upon degree of new construction required.

After total fixed costs are determined, gross income from the product is found by multiplying the estimated number of units produced during a year by the selling price of the item. Maximum allowable production cost per day then is determined by the formula

$$\frac{\text{Gross income - fixed cost}}{\text{No. working days per year}} = \text{maximum allowable operating cost per day}$$

Once this figure is obtained, it is compared with estimated

operating costs as determined in part C of the long form estimating guide. If these two figures are reasonably close to each other, it indicates the operation would warrant further investigation.

If this short method of estimating costs indicates the possibility of a practical operation, the owner then may find it desirable to go through the indicated long form and determine costs of an operation by close estimation. This procedure involves determining total fixed costs (part B), totaling operating costs (part C) on an annual basis, and comparing the sum of these items with the expected gross income.

Items listed under these major divisions of the outline are suggested as typical considerations for the average type of operation, but may not be adequate to cover all of the cost items. The outline is offered only as a guide to the method of attacking the problem, and careful consideration of factors applicable to the owner's individual situation is left to the owner himself. If further information is desired as to methods of estimating costs of an operation, the owner should consult certain excellent articles pertaining to the subject (6).

Rule of thumb method

1. Obtain estimates of cost of installed equipment.

2. Obtain total physical plant cost, which is found by taking two times the installed equipment cost for an operation housed in a new building.

3. Obtain total fixed cost, which is found by taking 20 percent of the total physical plant costs for a 10-year amortization or "write-off," or 30 percent of the total physical plant cost for a 5-year amortization or write-off.

4. Obtain gross income by multiplying the estimated number of units produced during the year by the expected selling price of the commodity.

5. Obtain an estimate of the total number of working days per year.

6. $\frac{\text{Gross income - fixed cost}}{\text{No. working days per year}}$ = maximum allowable operating costs per day

LONG FORM ESTIMATING GUIDE

	Installed cost	
A. PHYSICAL PLANT COSTS		
1. Total equipment costs	_____	
2. Site preparation	_____	
3. Building & building services	_____	
4. Process piping	_____	
5. Electrical installations	_____	
6. Utilities & service facilities	_____	
7. Contingencies & construction overhead	_____	
TOTAL PHYSICAL PLANT COSTS		_____

	Annual cost	
B. FIXED COSTS		
1. General overhead	_____	
2. Maintenance	_____	
3. Operating supplies	_____	
4. Depreciation costs	_____	
5. Taxes	_____	
6. Insurance	_____	
Total fixed costs		_____
C. OPERATING COSTS		
1. Raw materials	_____	
2. Utilities		
a) Electricity	_____	
b) Other power	_____	
c) Water & sewage	_____	
Total utilities	_____	
3. Direct costs		
a) Labor	_____	
b) Supervision	_____	
c) Payroll overhead	_____	
Total direct costs	_____	
Total operating costs		_____
TOTAL PRODUCTION COSTS (B + C)		_____

Conversion factors

The following conversion factors are provided for the convenience of the reader. They are average figures and can be used until detailed and specific data for an individual operation can be obtained.

Average Residues Developed Per Thousand Feet Board Measure of Lumber Manufactured (7)

Residues	Cubic feet	Tons (dry weight)
Western Oregon		
Coarse residue	32.1	0.443
Sawdust	20.5	0.283
Shavings	14.0	0.207
Bark	20.8	0.287
Total	87.4	1.220
Eastern Oregon		
Coarse residue	26.1	0.313
Sawdust	22.0	0.264
Shavings	9.4	0.113
Bark	23.3	0.279
Total	80.8	0.969

Volume (4)

	Cubic feet
Cord (standard)	128
Unit (standard; sawdust, hog fuel, pulp chips)	200
Solid wood content:	
1. One unit Douglas fir & western hemlock sawdust	80
2. One unit Douglas fir & western hemlock hogged fuel	72
3. One unit Douglas fir & western hemlock pulp chips	67

Chip recovery:	Units/M fbm logs
1. When picking clean wood	0.1 to 0.2
2. With slab debarker	0.25 to 0.3
3. With whole log debarker	0.5 to 0.575

Weight (4)

	Pounds
Cord (standard) green Douglas fir	6912
green western hemlock	7680
One unit Douglas fir sawdust	3700*
One unit Douglas fir hog fuel	4200*
One unit western hemlock hog fuel	4550*
One unit Douglas fir pulp chips	3300*
One unit western hemlock pulp chips	3900*
One bone dry unit (BDU) Douglas fir pulp chips	2400
One bone dry unit (BDU) Douglas fir pulp chips (uncompacted)	2000 to 2050

*Figures are based on average weights of secondary sawmill products, and are computed on basis of moisture content at which material is ordinarily utilized.

Example problems using rule of thumb method

The following two problems will illustrate use of the previously presented estimating forms and the formula for calculating maximum allowable operating cost. This method may be used for any operation listed in Figure 48, provided necessary data are available. In this example, consideration will be given only to a chipping operation.

Assume that two mills, identified as Mill A and Mill B, are considering the possibilities of installing chipper operations because of recent establishment of market outlets in their area. Both mills have similar production capacities and intended plant expansions. Calculations are made from the following data:

Working capital	Sufficient to consider idea
Production capacity	40 M fbm/day for 1 shift
Residue to produce 19 units of chips (dry weight)	17.7 tons or 1293 cu ft coarse residue
Average selling price of chips/unit	$7.00
No. working days/year	240

Chipping plant to be housed in separate building.

Estimated installed equipment prices are:

Barker, 30-inch	$10,000
Chipper and motor	7,500
Conveyor	8,000
Grinder for chipper blades and miscellaneous	3,000
Total	$28,500

To calculate cost of physical plant, equipment price is multiplied by 2.

$$\$28,500 \times 2 = \$57,000$$

Using the formula from page 79

$$\frac{\text{Gross income - fixed costs}}{\text{240 working days}} = \text{maximum allowable operating cost per day}$$

For gross income at $7/BDU

40 M fbm/day = 19 units of chips/day × $7 × 240 days = $31,920

If a 5-year write-off plan is used, the fixed cost at about 30 percent of total physical plant cost equals $17,100.

$$\frac{\$31,920 - \$17,100}{240} = \text{maximum allowable operating costs per day}$$

$$\frac{\$14,820}{240} = \$61.75 \text{ a day}$$

$$\frac{\$61.75}{19 \text{ units/day}} = \$3.25 \text{ a unit}$$

which is the maximum allowable operating costs per day, and includes raw materials, utilities, and direct costs.

Just what does this figure of $3.25 a unit mean to mill owners A and B? It is the break-even point, using the given rules of thumb for calculations.

When mill owner A carefully figured his operating costs (using C in the long form), he obtained a figure of $2.25 a unit—the difference between $3.25 and $2.25, or $1.00 per unit could be

considered as possible profit. Chipping at Mill A becomes a definite possibility, and an accurate survey now can be made of available market, selling price contracts, and detailed physical plant and production costs.

When mill owner B computed his operating costs, he arrived at a figure of $4.95 a unit. Chipping does not seem to be a feasible choice at this time for Mill B, and other utilization possibilities should be investigated. If, after sufficient thought, chipping still seems to be the most logical use of mill wastes, an accurate survey (the same as at Mill A) may prove that operating costs are within range.

In this section the sawmill owner has been presented with the tools necessary for a primary look into possible utilization methods. If there is even a slight suggestion of success he should continue with a thorough step-by-step analysis.

Transportation

It is now possible for mills having chip contracts to negotiate with a railroad for specially contracted rates. These rates are set up on a point-to-point basis, and apply only for shipment between specified points; i.e., Eugene-Toledo, Roseburg-Toledo, Eugene-Longview, or Portland-Longview. Where no specially contracted rates exist between mill and railroad, chip shipments are charged on a mileage basis. The following table is set up on price ranges determined from supplement 16 to rate tariff 237-Q, effective December 2, 1957 (courtesy Southern Pacific Railroad). More complete information may be secured through railroad companies. Rates apply only to intrastate traffic.

Intrastate Rates on Chip Shipments

Distance in miles	Prices in cents per 200 cu ft unit of chips
One to and including 25	198 to 237
Over 25 to and including 50	247 to 330
Over 50 to and including 100	349 to 438
Over 100 to and including 175	458 to 547
Over 175 to and including 275	567 to 718
Over 275 to and including 400	766 to 986

Examples of Point-To-Point Rates

From	To	Cost per 200 cu ft unit
Corvallis	Toledo	1.84
Springfield		2.61
Roseburg		3.49
Coos Bay		4.44
Klamath Falls	Longview, Wash.	12.77
Springfield		8.14
Portland		3.60
Corvallis		8.34
Roseburg	Millersburg	2.84
Glendale		4.45
Cottage Grove		1.89
Eugene		1.89
Coos Bay		3.88

A 40-foot, open-top chip car will carry from 16 to 18.5 standard units of chips, while a 50-foot chip car will carry from 20 to 23 units (4).

Transportation costs play a large role in determining the final return for a product. Simple logic will show that in shipping low-cost items to distant markets, rail rates become a prohibitive factor. Any advantage a mill might gain through low manufacturing costs could be offset easily by competitors closer to markets having lower shipping rates.

Where it is not possible to transport economically by rail, the sawmill owner should consider trucking. Everything from long-distance hauling to purchase of vehicles (for local distribution) is open to examination.

BIBLIOGRAPHY

1. Anderson, W.C., and A.S. Todd, An Appraisal of Methods For Salvaging Small Sawmill Residues in the Southeast, Station Paper No. 84. College Station, Texas: Southeastern Forest Experiment Station, November 1957.

2. Brumley, G.W., and C. Mathewson, Economics of Wood Chip Utilization, Unpublished speech. Georgia: St. Mary's Kraft Corporation.

3. Coats, M.W., De-Barking and Chipping Report, Unpublished. Bend, Oregon: Brooks-Scanlon, Inc, September 1957.

4. Conversion Factors For Pacific Northwest Forest Products, Pullman, Washington: Institute of Forest Products, 1951.

5. Cooke, W.H., Consolidated Products From Wood Residues, Report N.L. 2. Corvallis: Oregon Forest Products Laboratory Report, April 1, 1953.

6. Coolidge, L.D., and J.R. Pfeiffer, Cost Estimating for Wood Industries, Information Circular 9. Corvallis: Oregon Forest Products Laboratory, May 1956.

7. Corder, S.E., Oregon Mill Residues in 1953, Information Circular 7. Corvallis: Oregon Forest Products Laboratory, May 1956.

8. Corder, S.E., and D.R. Gedney, Mill Residues in 3 Oregon Counties, Information Circular 8. Corvallis: Oregon Forest Products Laboratory and Pacific Northwest Forest and Range Experiment Station, April 1, 1956.

9. Heritage, C.C., "Reducing Wood Waste," TAPPI, August 1954.

10. Horne, R.C., Utilization of Sawdust and Shavings, Research Note No. 7.231. Portland, Oregon: Western Pine Association, May 1950.

11. Hunt, D.L., Agricultural Uses for Wood Residues, Research Note No. 7.232. Portland, Oregon: Western Pine Association, September 1955.

12. More Wood With Less Men Through Closer Utilization, Release No. 298. New York: American Pulpwood Association, May 1957.

13. Sarvis, J.C., Bark Utilization Study, Research Note No. 7.221. Portland, Oregon: Western Pine Association, March 1954.

14. Survey of Equipment for Edge-Gluing of Lumber, Research Note No. 4411. Portland, Oregon: Western Pine Association, July 1957.

15. The Utilization of Wood Residues for Pulp Chips, Bulletin No. 49. College Station: Texas Forest Service, November 1956.

16. Uses for Sawdust and Shavings, Report No. R1666-1. Madison, Wisconsin: U.S. Forest Products Laboratory, 1952.

17. Voorhies, G., An Inventory of Sawmill Waste in Oregon, Bulletin No. 17. Corvallis: Oregon State College Engineering Experiment Station, July 1942.

18. Wood Composition Board. Portland, Oregon: Pacific Power and Light Company, December 1955.

19. Wood Residue Utilization Study, Report No. S550/1. Seattle, Washington: Sandwell and Company, Oregon Development Commission, May 1957.

REFERENCES

Agricultural Uses

Hunt, D.L., Agricultural Uses for Wood Residues, Research Note No. 7.232. Portland, Oregon: Western Pine Association, September 1955.

McIntyre, A.C., Wood Chips for the Land, Leaflet No. 323. Washington, D.C.: U.S. Department of Agriculture Soil Conservation Service, June 1952.

Sawdust - Shavings

Buckley, E.H., "Wood Flour Production in Canada," Canada Lumberman, May 1952.

Sawdust Floor-Sweeping Compounds, Report No. R1666-14. Madison, Wisconsin: U.S. Forest Products Laboratory, October 1947.

Sawdust-Cement Concrete, Report No. R1666-15. Madison, Wisconsin: U.S. Forest Products Laboratory, 1952.

Edge and End Gluing

Economics of End Jointing Ponderosa Pine Boards, Research Note No. 7342. Portland, Oregon: Western Pine Association.

End Gluing Ponderosa Pine With Butt Joints, Research Note No. 7.315. Portland, Oregon: Western Pine Association.

Upgrading Ponderosa Pine Lumber by the Edge Gluing Process, Research Note No. 6321. Portland, Oregon: Western Pine Association.

Upgrading Sugar Pine Lumber by the Edge Gluing Process, Research Note No. 7.324. Portland, Oregon: Western Pine Association.

Upgrading Western Red Cedar Lumber by the Edge Gluing Process, Research Note No. 6322. Portland, Oregon: Western Pine Association.

Seasoning

Knauss, A.C., Dry Kilns for Small Sawmill Operations, for presentation at Northwest Wood Products Clinic. Portland, Oregon: Pacific Northwest Forest and Range Experiment Station, April 1949.

Togeson, O.W., A Small House - Furnace Lumber Dry Kiln, Report No. 1776. Madison, Wisconsin: U.S. Forest Products Laboratory, 1956.

Articles

Articles on Wood Chips, Chipping, and Chippers, Research Note No. 7.242. Portland, Oregon: Western Pine Association, April 1957.

West, W.I., Index of Selected Journal Articles Pertaining to the Lumber Industry. Corvallis: Oregon State College Cooperative Association, 1957.

Finger Jointing

Jones, Bill, "Finger Jointing Adds Carload of Usable Lumber Per Week," Wood and Wood Products, September 1957.

Miscellaneous

Cooke, W.H., Sheathing Board From Ponderosa Pine Mill Residues, Report No. L-4. Corvallis: Oregon Forest Products Laboratory, September 1954.

Cut-Stock Possibilities in Wood-Consuming Industries in Mid-Western States, Report No. D1724. Madison, Wisconsin: U.S. Forest Products Laboratory, September 1948.

Equipment

"Buyers Guide Section," every issue of Lumberman's Magazine or Timberman's Magazine.

APPENDIX

REGIONAL LUMBER ASSOCIATIONS

California Redwood Association
576 Sacramento Street
San Francisco 11, California

Douglas Fir Plywood Association
1119 A Street
Tacoma 2, Washington

West Coast Lumbermen's Association
1410 SW Morrison Street
Portland 5, Oregon

Western Pine Association
510 Yeon Building
Portland 4, Oregon

PUBLIC RESEARCH ORGANIZATIONS

U.S. Forest Products Laboratory
Madison, Wisconsin

Institute of Forest Products
State of Washington
313 Anderson Hall
Seattle 5, Washington

Forest Products Research Center
Corvallis, Oregon

California Forest Products Laboratory
Berkeley, California

British Columbia Forest Products Laboratory
Vancouver, B.C.

ABBREVIATED EQUIPMENT QUESTIONNAIRE

Company name _____

Type of equipment _____

Equipment:

- Floor space requirements _____
- Maximum opening _____
- Minimum opening _____
- Max & min length _____
- Power requirements (hp) _____
- *Amount of residue produced/unit product _____
- *Production capacity/8-hr shift _____
- No. men required to operate _____
- Operating cost exclusive of labor/8-hr shift _____
- Approximate weight _____

Cost:

- Cost of equipment, FOB _____
- Estimated cost of equipment delivered to _____
- Estimated cost of installation at _____

Our interest areas

Installations:

- Barkers _____
- Chippers _____
- Hogged fuel _____
- End & edge gluing _____
- Other _____

Equipment:

- Barkers _____
- Chippers _____
- Hogs _____
- Radio frequency gluing _____
- Slashers _____
- Fixed trim saws _____
- Conveyors, blowers, chains _____
- Other _____
- Flakers _____

Remarks:

_____

_____

_____

*Mill owner fills in this information for benefit of manufacturer.

OREGON STATE COLLEGE
ENGINEERING EXPERIMENT STATION
CORVALLIS, OREGON

PARTIAL LIST OF PUBLICATIONS

(For a complete listing write the Engineering Experiment Station.)

Bulletins—

No. 18. The Use of the Fourier Series in the Solution of Beam Problems, by B. F. Ruffner. 1944. 50¢.

No. 19. 1945 Progress Report on Pollution of Oregon Streams, by Fred Merryfield and W. G. Wilmot. 1945. 40¢.

No. 20. The Fishes of the Willamette River System in Relation to Pollution, by R. E. Dimick and Fred Merryfield. 1945. 40¢.

No. 21. The Use of the Fourier Series in the Solution of Beam-Column Problems, by B. F. Ruffner. 1945. 25¢.

No. 22. Industrial and City Wastes, by Fred Merryfield, W. B. Bollen, and F. C. Kachelhoffer. 1947. 40¢.

No. 23. Ten-Year Mortar Strength Tests of Some Oregon Sands, by C. E. Thomas and S. H. Graf. 1948. 25¢.

No. 24. Space Heating by Electric Radiant Panels and by Reverse-Cycle, by Louis Slegel. 1948. 50¢.

No. 25. The Banki Water Turbine, by C. A. Mockmore and Fred Merryfield. Feb 1949. 40¢.

No. 26. Ignition Temperatures of Various Papers, Woods, and Fabrics, by S. H. Graf. Mar 1949. 60¢.

No. 27. Cylinder Head Temperatures in Four Airplanes with Continental A-65 Engines, by S. H. Lowy. July 1949.

No. 28. Dielectric Properties of Douglas Fir at High Frequencies, by J. J. Wittkopf and M. D. Macdonald. July 1949. 40¢.

No. 29. Dielectric Properties of Ponderosa Pine at High Frequencies, by J. J. Wittkopf and M. D. Macdonald. September 1949. 40¢.

No. 30. Expanded Shale Aggregate in Structural Concrete, by D. D. Ritchie and S. H. Graf. Aug 1951. 60¢.

No. 31. Improvements in the Field Distillation of Peppermint Oil, by A. D. Hughes. Aug 1952. 60¢.

No. 32. A Gage for the Measurement of Transient Hydraulic Pressures, by E. F. Rice. Oct 1952. 40¢.

No. 33. The Effect of Fuel Sulfur and Jacket Temperature on Piston Ring Wear as Determined by Radioactive Tracer, by M. Popovich and R. W. Peterson. July 1953. 40¢.

No. 34. Pozzolanic Properties of Several Oregon Pumicites, by C. O. Heath, Jr. and N. R. Brandenburg. 1953. 50¢.

No. 35. Model Studies of Inlet Designs for Pipe Culverts on Steep Grades, by Malcolm H. Karr and Leslie A. Clayton. June 1954. 40¢.

No. 36. A Study of Ductile Iron and Its Response to Welding, by W. R. Rice and O. G. Paasche. Mar 1955. 60¢.

No. 37. Evaluation of Typical Oregon Base-Course Materials by Triaxial Testing, by M. A. Ring, Jr. July 1956. 50¢.

No. 38. Bacterial Fermentation of Spent Sulfite Liquor for the Production of Protein Concentrate Animal Feed Supplement, by Herman R. Amberg. Oct 1956. 50¢.

No. 39. Wood Waste Disposal and Utilization, by R. W. Boubel, M. Northcraft, A. Van Vliet, M. Popovich. Aug. 1958. $1.00

Circulars—

No. 16. Water Works Operators' Manual, by Warren C. Westgarth. Mar 1953. 75¢.

No. 17. Proceedings of the 1953 Northwest Conference on Road Building. July 1953. 60¢.

No. 18. Proceedings of the 1955 Northwest Conference on Road Building. June 1955. 60¢.

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